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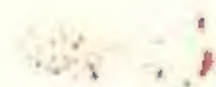
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A TEXTBOOK OF MINERALOGY

Asian Students Edition



School of Archaeology.

A TEXTBOOK
OF
MINERALOGY

WITH AN EXTENDED TREATISE ON
CRYSTALLOGRAPHY AND PHYSICAL
MINERALOGY

17846
RT

EDWARD SALISBURY DANA

Late Professor Emeritus of Physics, Yale University

FOURTH EDITION, REVISED AND ENLARGED

BY

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Sheffield Scientific School of Yale University*

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PREFACE TO THE FOURTH EDITION

It is only a little over ten years since the third edition of this book was published. This period, however, has been one of such active mineralogical investigation that a new edition seemed desirable. The fourth edition, therefore, endeavors to present the important facts of the science as known on January 1, 1932. The changes in the book are essentially as follows: In Part I on Crystallography a section of some seventeen pages has been added on crystal structure and the methods of its investigation by means of X-rays. The remainder of this section remains substantially unchanged. Parts II and III on Physical and Chemical Mineralogy have been revised but have had only minor additions. Part IV on the Origin, Mode of Occurrence and Association of Minerals is new to this book. Part V has been entirely revised. Descriptions of about two hundred and twenty new species have been added. The attempt has been made to give a brief but complete statement of the important facts now known about all well-defined mineral species. In addition brief mention is made of doubtful species or those which have recently been discredited. It is realized that such a complete treatment of the subject would not normally have its place in a book of this character. At the present time, however, there is no book available that gives such a survey of the subject and until such a book is at hand it is thought that the inclusion here of brief descriptions of all known minerals will be of value. As far as possible simple statements of the results of the investigation of mineral structure by means of X-rays have been included in the mineral descriptions. The paragraphs on occurrence have been largely rewritten. In the case of the commoner minerals a careful selection of the localities of their occurrence has been made in order to give only those of most importance either from a scientific or economic point of view. In the case of rarer species all known localities have been mentioned. As far as possible the locality names have been checked, the spelling used by the *Times Atlas* having been followed in most instances. In the case of the south-central European countries, alternative names for the same place have been frequently given.

The mineral data presented have been gathered from the periodical literature, etc., and from many texts. Among the books which have been of particular value are the following: Doelter's *Handbuch der Mineralchemie*, Hintze's *Handbuch der Mineralogie*, *Lehrbuch der Mineralogie* by Niggli, *Mineralogy* by Miers-Bowman, and especially Winchell's *Elements of Optical Mineralogy* and Larsen's *Microscopic Determination of the Nonopaque Minerals*. The editor is also indebted to Professor Esper S. Larsen for the privilege of consulting the manuscript of the new edition of the last-named work. He also acknowledges gratefully many valuable suggestions made by Professor Charles Palache.

WILLIAM E. FORD

PREFACE TO THE THIRD EDITION

The first edition of this book appeared in 1877 and approximately twenty years later (1898) the second and revised edition was published. Now, again after more than twenty years, comes the third edition. The changes involved in the present edition are chiefly those of addition, the general character and form of the book having been retained unchanged. In the section on Crystallography the important change consists in the introduction of the methods employed in the use of the stereographic and gnomonic projections. A considerable portion of the section on the Optical Characters of Minerals has been rewritten in the endeavor to make this portion of the book simpler and more readily understood by the student. In the section on Descriptive Mineralogy all species described since the previous edition have been briefly mentioned in their proper places. Numerous other changes and corrections have, of course, been made in order to embody the results of mineral investigation during the last two decades. Only minor changes have been made in the order of classification of the mineral species. It was felt that as this book is so closely related to the System of Mineralogy it was unwise to attempt any revision of the chemical classification until a new edition of that work should appear. The description of the methods of Crystal Drawing given in Appendix A has been largely rewritten. A new table has been added to Appendix B in which the minerals have been grouped into lists according to their important basic elements. Throughout the book the endeavor has been to present in a clear and concise way all the information needed by the elementary and advanced student of the science.

The editor of this edition is indebted especially to the published and unpublished writings of the late Professor Samuel L. Penfield for much material and many figures that have been used in the sections on Crystallography and The Optical Character of Minerals. He also acknowledges the cordial support and constant assistance given him by Professor Edward S. Dana.

WILLIAM E. FORD

NEW HAVEN, CONN., Dec. 1, 1921

PREFACE TO THE SECOND EDITION

The remarkable advance in the Science of Mineralogy, during the years that have elapsed since this Text-Book was first issued in 1877, has made it necessary, in the preparation of a new edition, to rewrite the whole as well as to add much new matter and many new illustrations.

The work being designed chiefly to meet the wants of class or private instruction, this object has at once determined the choice of topics discussed, the order and fullness of treatment and the method of presentation.

In the chapter on Crystallography, the different types of crystal forms are described under the now accepted thirty-two groups classed according to their symmetry. The names given to these groups are based, so far as possible, upon the characteristic form of each, and are intended also to suggest the terms formerly applied in accordance with the principles of hemihedrism. The order adopted is that which alone seems suited to the demands of the elementary student, the special and mathematically simple groups of the isometric system being described first. Especial prominence is given to the "normal group" under the successive systems, that is, to the group which is relatively of most common occurrence and which shows the highest degree of symmetry. The methods of Miller are followed as regards the indices of the different forms and the mathematical calculations.

In the chapters on Physical and Chemical Mineralogy, the plan of the former edition is retained of presenting somewhat fully the elementary principles of the science upon which the mineral characters depend; this is particularly true in the department of Optics. The effort has been made to give the student the means of becoming practically familiar with all the modern methods of investigation now commonly applied. Especial attention is, therefore, given to the optical properties of crystals as revealed by the microscope. Further, frequent references are introduced to important papers on the different subjects discussed, in order to direct the student's attention to the original literature.

The Descriptive part of the volume is essentially an abridgment of the Sixth Edition of Dana's System of Mineralogy, prepared by the author (1892). To this work (and future Appendices) the student is, therefore, referred for fuller descriptions of the crystallographic and optical properties of species, for analyses, lists of localities, etc.; also for the authorities for data here quoted. In certain directions, however, the work has been expanded when the interests of the student have seemed to demand it; for example, in the statement of the characters of the various isomorphous groups. Attention is also called to the paragraph headed "Dist." in the description of each common species, in which are given the distinguishing characters, particularly those which serve to separate it from other species with which it might be easily confounded.

The list of American localities of minerals, which appeared as an Appendix in the earlier edition, has been omitted, since in its present expanded form

it requires more space than could well be given to it, further, its reproduction here is unnecessary since it is accessible to all in printed not only in the *System of Mineralogy* but also in separate form. A full topical index has been added, besides the usual Index of Species.

The obligations of the present volume to well-known works of other authors — particularly to those of Smith and Rosenbusch — are too obvious to require special mention. The author must however express his gratitude to his colleague, Prof. L. V. Pirsson, who has given him material aid in the part of the work dealing with the optical properties of minerals as examined under the microscope. He is also indebted to Prof. S. L. Penfield of New Haven and to Prof. H. A. Miers of Oxford, England, for various valuable suggestions.

EDWARD SALISBURY DANA

NEW HAVEN, CONN., Aug. 1, 1898

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INTRODUCTION

1. The Science of Mineralogy treats of those inorganic species called minerals which together in rock masses or in isolated form make up the material of the crust of the earth, and of other bodies in the universe so far as it is possible to see them in the form of meteorites.

2. **Definition of a Mineral.** - A Mineral is a body produced by the processes of inorganic nature, having usually a definite chemical composition and if formed under favorable conditions, a certain characteristic atomic structure which is expressed in its crystalline form and other physical properties.

This definition calls for some further explanation.

First of all, a mineral must be a homogeneous substance, even when minutely examined by the microscope. Further, it must have a chemical composition which commonly is definite and can be expressed by a chemical formula. In some cases the chemical composition is variable but only within certain limits and then usually according to a definite law. Thus, much basalt appears to be homogeneous to the eye, but when examined under the microscope in thin sections it is seen to be made up of different substances, each having characters of its own. Again, obsidian, or volcanic glass, though it may be essentially homogeneous, has not a sufficiently definite composition to be classed as a mineral.

Again, a mineral has in most cases a definite atomic structure. This atomic structure, as will be shown later, manifests itself in the physical characters and especially in the external crystalline form. A mineral, in the majority of cases, possesses both general properties, such as composition, specific gravity, melting point, etc. and directional properties, such as its atomic structure, crystal symmetry, optical characters, etc. The combination of these two kinds of characters serves to define a mineral species.

It is customary, as a matter of convenience, to limit the name mineral to those compounds which have been formed by the processes of nature alone, whereas compounds made in the laboratory or the smelting furnace are at best called artificial minerals. Further, mineral substances which have been produced through the agency of organic life are not included among minerals, as the pearl of an oyster, etc. Finally, mineral species are, as a rule, limited to solid substances; the only liquids included being metallic mercury and water. Petroleum is not properly a homogeneous substance, consisting rather of several hydrocarbon compounds; it is hence not a mineral species.

It is obvious from the above that minerals, in the somewhat restricted sense usually adopted, constitute only a part of what is often called the Mineral Kingdom.

3. **Scope of Mineralogy.** In the following pages, the general subject of mineralogy is treated under the following heads:

1. **Crystallography.** - This comprises a discussion of crystals in general and especially of the crystalline forms of mineral species.

(2) *Physical Mineralogy* — This includes a discussion of the physical characters of minerals, that is those depending upon cohesion and elasticity, density, light, heat, electricity, and so on.

(3) *Chemical Mineralogy* — Under this head are presented briefly the general principles of chemistry as applied to mineral species. Their characters as chemical compounds are described, also the methods of investigating them from the chemical side by the blowpipe and other means.

(4) *Occurrence of Minerals* — This section includes a brief description of the different modes of mineral occurrence, characteristic minerals, associations, etc.

(5) *Descriptive Mineralogy* — This includes the classification of minerals and the description of each species with its varieties, especially in its relations to closely allied species as regards crystalline form, physical and chemical characters, occurrence, nature, and other points.

4. *Literature.* — Reference is made to the Introduction to the Sixth Edition of Dana's System of Mineralogy, pp. xiv-xv, for an extended list of important works on Mineralogy up to 1892 and to its Appendices I, II and III for works published up to 1913; the names are also given of many scientific journals which contain original memoirs on mineralogical subjects. For the convenience of the student the titles of a few works, mostly of a general character, are given here. Further references to the literature of Mineralogy are introduced through the first half of this work, particularly at the end of sections dealing with special subjects.

Crystallography and Physical Mineralogy

FAVORITE WORKS* include those of Boué, Le Bail, 1773; Haüy, 1822; Neumann, *Krystallographie*, 1823, and *Krystallographie*, 1827; K. Müller, 1825; Weissmann, *Krystallographie*, 1829; Naumann, 1829 and later; Quenstedt, 1840; de la Roche, 1850 and 1854; Friedl., 1855; Kopp, 1868; von Lang, 1868; Bravais, *Éléments de Cryst.*, Paris, 1866-1843; Schmalz, 1891-94; *Revue scientifique*, 1873.

FAVORITE WORKS include the following.

Barker. *Crystalline and Tabular Methods in Crystallography*, 1922. *Systematic Crystallography*, 1910.

Day. *Elementary Crystallography*, 1919.

De la Roche. *Introduction to Crystallography*, 1915.

Beckenkamp. *Statistik der chemischen Krystallographie*, 1913-1915.

Broha. *Handbuch der Kristallographie*, 1902.

Goldschmidt. *Index der Kristallformen der Mineralien*; 3 vols., 1896-01. *Anwendung der Linienprojektion zur Berechnung der Kristalle*, 1897. *Krystallographische Werke*, 1907. *Atlas der Kristallformen*, 1913-1915.

Goldschmidt and Gordon. *Crystallographic Tables for the Determination of Minerals*, 1928.

Göppert. *Kristallbeschreibung und Kristallrechnung*, 1914.

Groth. *Physikalische Kristallographie und Einführung in die kristallographische Kenntnis der wichtigsten Mineralarten*, 1905; *Elemente der Physik und Chem. und Kristallographie*, 1917.

Haidinger. *Icones Figurarum Crystallinarum*, 1927.

Keil. *Einleitung in die Kristallographie*, 1876.

Lewis. *Crystallography*, 1899.

Lichsch. *Geometrische Kristallographie*, 1891. *Physikalische Kristallographie*, 1899.

Mallard. *Traité de Cristallographie géométrique et physique*, vol. 1, 1879; vol. 2, 1884.

* The full titles of many of these are given in pp. 8-10 of Dana's System of Mineralogy, 1892.

- Moses. *Character of Crystals*, 1899.
 Niggli. *Lehrbuch der Mineralogie*, Vol. I, 1924, Vol. II, 1926, *Krystallographische und strukturelle Geologie*, 1928.
 Parker. *Kristallografien*, 1920.
 Recks. *How to Draw Crystals*, 1908.
 Reinhard. *Universum Drehtische*, Bonn, 1931.
 Schöckel. *Angewandte Krystallographie*, Ruse's *Krystallographie*, II. Band, 1879.
 Schöckel. *Über eine neue Herleitung und Nomenklatur der 230 kristallographischen Raumgruppen*, 1929.
 Schreede and Schneider. *Röntgenspektroskopie und Kristallstrukturanalyse*, 1929.
 Schoenflies. *Theorie der Kristalle*, 1925.
 Schöckel. *Entwicklung einer Theorie der Kristallstruktur*, 1929.
 Sommerfeldt. *Geometrisches Kristallgitter*, 1906, *Physikalisches Kristallgitter*, 1907, *The Crystallography*, 1911.
 Story Marksteyn. *Crystallography, the Morphology of Crystals*, 1895.
 Tutton. *Crystals as Solids and Chemical Compounds*, 1929, *Crystallography and Physical Crystal Mineralogy*, 1922, *The Natural History of Crystals*, 1924.
 Viola. *Crystallography*, 1904.
 Wulker. *Crystallography*, 1913.
 Wulster. *Crystallography*, 1909.
 Wulster. *Angewandte Kristallprojektion zum Berechnen der Kristalle* (Hesse's *Krystallographie* III. Band), 1907.
 Williams. *Fundamentals of Crystallography*, 1906.
 Wulff. *Die 32 kristallographischen Symmetrieklassen und ihre einfachen Formen*, 1914.

In Physics and Mineralogy the most important general works are those of Schöckel (1898, 1904, 1911, 1929), Tutton (1922, 1924), and the *Handbuch der Mineralogie* etc. (1893). Important later works include the following:

- Davy-Farnham. *Microscopic Examination of the Ore Minerals*, 1920.
 Duparc and Pearson. *Traité de Technique Minéralogique et Pétrographique*, 1907.
 Farnham. *Determination of the Opaque Minerals*, 1931.
 Gerd. *Physikalisches Kristallgitter*, 1903.
 Gerd-Jackson. *On the Structure of Crystals*, 1900.
 Johansen. *Determination of Rock-forming Minerals*, 1909, *Manual of Petrographic Methods*, 1914, *Essentials of the Microscopic Determination of Rock-forming Minerals and Rocks in Thin Sections*, 1922.
 Larsen. *Microscopic Determination of the Nonopaque Minerals*, 1921.
 Murdoch. *Microscopic Determination of the Opaque Minerals*, 1916.
 Natta, translated into French by Duparc and de Dervin. *La Méthode Universelle de l'Essai*, 1914.
 Schusterhöhn and Ramdohr. *Lehrbuch der Petrographie*, 1931, *Petrographische Bestimmungstabellen*, 1931.
 Short. *Microscopic Determination of the Ore Minerals*, I. & Geol. Soc. Bull. 825, 1931.
 Winchell. *Elements of Optical Mineralogy*, 1929, 1931.
 Wright. *The Methods of Petrographic Microscopic Research*, 1911.

General Mineralogy

Of the many works, a knowledge of which is needed by one who wishes a full acquaintance with the mineral terminology of Mineralogy, the following are particularly important. Very early works include those of Theophrastus, Pliny, Lucanus, Wallerius, Cronstedt, Werner, Bergmann, Klaproth.

Works of the nineteenth century: Haüy's *Traité*, 1801-1822, Jameson 1810, 1820; Werner's *Lehrbuch der Mineralogie*, 1817, *Chemische Mineralogie*, 1819, 1821, *Lehrbuch der Mineralogie*, 1823, 1825, *Mineralogie*, 1827, Haüy's *Annuaire de Minéralogie*, 1824, *Breithaupt's Charakteristik*, 1820, 1823, 1832, *Berthel's Geschichte*, 1824, 1832, *Plücker's Min.*, 1822, 1827, *Shufeldt's Min.*, 1832, 34, and later editions, von Kober's *Lehrbuch*, 1838, *Moos's Min.*, 1830, *Breithaupt's Min.*, 1836-1847, *Handwörterbuch*, 1835, *Neumann's Min.*, 1846 and over, *Haumann's Handbuch*, 1847, *Dufrenoy's Min.*, 1844-1847 (also 1850-1859), *Brooke & Miller*, 1852, *J. D. Dana's System* of 1837, 1844, 1850, 1854, 1869.

More Recent Works are the following:

- Bauer. Lehrbuch der Mineralogie. 1904.
 Baerman. Text-Book of Descriptive Mineralogy. 1884
 Baumbauer. Das Reich der Krystalle. 1889.
 Bayley. Descriptive Mineralogy. 1917
 Blum. Lehrbuch der Mineralogie. 4th ed. 1873-1874
 Brauns. Die Mineralogie. 1903. English translation by Spencer, 1913.
 Clarke. The Data of Geochemistry. 1924
 Dana, E. S. Dana's system of Mineralogy 6th ed. New York. 992. Appendix I, 1899, II, 1900. III, 1915. Also elementary Minerals and How to study them, New York, 1905
 Dana-Ford. Manual of Mineralogy. 1920.
 Des Cloizeaux. Manuel de Mineralogie, vol. 1, 1892, vol. 2, 1er fasc. 1874. 2me. 1893
 Groth and Mielertner. Mineralogische Tabellen. 1921.
 Hantzsch. Handbuch der Mineralogie. 1889-1901
 Idings. Rock Minerals. 1900.
 Kraus and Hunt. Mineralogy. 1929
 Lacroix. Mineralogie de la France et du Maroc, 6 vols. 1893-1913
 Miers-Bowman. Mineralogy. 1925
 Moses and Parsons. Mineralogy, Crystallography and Blowpipe Analysis. 1910.
 Merrill. The Non-metallic Minerals. 1904
 Nagel. Lehrbuch der Mineralogie. 1924-1926.
 Phillips. Mineralogy. 1912
 Rogers. Study of Minerals. 1921
 Schrauf. Atlas der Krystall-Formen des Mineralreiches, 4to, vol. 1, A-C, 1865-1877
 Spencer. The Western Minerals. 1911
 Tschermak. Lehrbuch der Mineralogie. 1884, 4th ed. 1923
 Weinbach. Synopsis Mineralogie oder einer sehr compacten Mineralgeschichte. 1878
 Zirkel. 4th ed. 1904. Name of a Mineralogy. Leipzig. 1897
 Wülfing. Die Metastasen-Verhältnisse, etc. 1907. further works on related subjects, see Dana's system, p. 34

For a catalogue of localities of minerals in the United States and Canada see the volume 61 pp. referred from Dana's system. 6th ed. See also the volume of the Mineral resources of the United States, 1st ed. since 1882 under the auspices of the U. S. Geological Survey and U. S. Bureau of Mines

Chemical and Determinative Mineralogy

- Bischoff. Lehrbuch der chemischen und physikalischen Geologie. 1847-54, 2d ed. 1893 6th. (Also an English ed. 1901)
 Blum. Die Petrographischen der Mineralreiche. 1903. With 4 Nachträge. 1947, 176
 Brush-Penfield. Manual of Determinative Mineralogy with an Introduction on Blow pipe Analysis. 1906
 Dander. Allgemeine chemische Mineralogie. Leipzig. 1890. Handbuch der Mineralogie. 1912-13
 Duparc and Monnier. Traité de Technique Minéralogique et Pétrigraphique. 1913
 Saké. Mineral Tables for the Determination of Minerals by their Physical Properties. 1904
 Erdlich. Manual of Quantitative Blowpipe Analysis. New York. 1892
 Kobell, F. von. Tafeln zur Bestimmung der Mineralien mittelst ein sehr chemischer Verfahrn auf trockenem und nassem Wege. 11te Aufl. 1878
 Kraus and Hunt. Tables for the Determination of Minerals. 1900
 Lewis and Hawkins. A Manual of Determinative Mineralogy. 1931
 Putnam. A chart showing the chemical characters of the Mineral Kingdom. 1927
 Rammeisberg. Handbuch der kristallographisch-physikalischen Chemie. Leipzig. 1891-92. Handbuch der Mineralchemie. 2d ed. 1875. English ed. 1899. 2 1906
 Rosenholtz and Smith. Tables and Charts of Specific Gravity and Hardness for use in the Determination of Minerals. 1931
 Roth. Allgemeine chemische Geologie. vol. 1, Bildung u. Umhüllung der Mineralien, etc. 1878. 2. Petrographie. 1887-1890
 Webely. Die Mineral-Spezies nach der für das spezifische Gewicht derselben angenommenen und gefundenen Werthen, Graz, 1868.

Weisbach. Tabellen zur Bestimmung der Mineralen nach äusseren Kennzeichen, 3te Auflage 1880. Also founded on Weisbach's work, *Frisz's Tables for the determination of minerals*, 4th ed. 1897.

Artificial Formation of Minerals

- Dittler. Mineralogisches Praktikum, 1915.
 Gurli. *Technique der parageneten künstlichen Mineralien, namentlich der kristallinen Hartenzeugnisse*, 1857.
 Fuchs. Die künstlich erzeugten Mineralien, 1872.
 Daubrée. *Essai systématique de l'évolution expérimentale*, Paris, 1879.
 Fouqué and M. Lévy. *Synthèse des Minéraux et des Roches*, 1882.
 Bourgeois. *Réproduction artificielle des Minéraux*, 1884.
 Meunier. *Les échantillons de minéraux synthétiques*.
 Vogt. *Die Silikatschmelzen*, 1885-1904.

Mineralogical Journals

The following Journals are largely devoted to original papers on Mineralogy

- Amer. Min. *American Mineralogist*, 1906.
 Bull. Soc. Min. *Bulletin de la Société Française de Minéralogie*, 1878.
 Centr. bl. Min. *Centralblatt für Mineralogie, Geologie und Paläontologie*, 1900.
 Chem. Erde. *Chemie der Erde*, 1913.
 Fortsch. Min. *Fortschritte der Mineralogie, Kristallographie und Petrographie*, 1911.
 Jb. Min. *Neues Jahrbuch für Mineralogie, Geologie und Paläontologie, etc.*, from 1833.
 Min. Mag. *The Mineralogical Magazine and Journal of the Mineralogical Society of Great Britain*, 1840.
 Min. Mitth. *Mineralogische und petrographische Mittheilungen*, 1878-. Earlier, from 1811 *Mineralogische Mittheilungen* von C. F. Schumacher.
 Rev. Min. *Revue de Minéralogie et Cristallographie*, 1887-1915.
 Zs. Kr. *Zeitschrift für Kristallographie und Mineralogie*, 1877.

ABBREVIATIONS

Ax. pl.	Plane of the optic axis	H.	Habit
Ex. Br.	Angle between x and y	Obs.	Observation on occurrence, etc.
Br.	Optic bisection x and y	O.P.	Optic Plane p. 362
B.B.	Habit on the blowpipe p. 363	Pyr.	Pyriformity of blowpipe and other characters
Comp.	Composition	R.F.	Refracting Plane p. 362
Diff.	Differences, or distinctive characters	Var.	Varieties
G.	Specific Gravity.		

The sign \wedge is used to indicate the angle between two faces of a crystal, as $am \wedge 110$ or $44^\circ 30'$.

PART I. CRYSTALLOGRAPHY

GENERAL MORPHOLOGICAL RELATIONS OF CRYSTALS

5. Crystallography.—The subject of Crystallography includes the description of the characters of crystals in general, of their internal or atomic structure, of the various forms of crystals and their division into classes and systems, of the methods of studying crystals, including the determination of the mathematical relations of their faces and the measurement of the angles between them, finally, a description of compounds of two crystals, of irregularities in crystals, of crystalline aggregates and of pseudomorphous crystals.

6. Definition of a Crystal.—A crystal is the regular pointation form, bounded by smooth surfaces, which is assumed by a chemical compound under the action of its interatomic forces, when passing, under suitable conditions, from the state of a liquid or gas to that of a solid.

As expressed in the foregoing definition, a crystal is characterized, first, by its definite internal structure, and, second, by its external form. A crystal is the normal form of a chemical species, as of all solid chemical compounds, but the crystal was suitable for the formation of a crystal of ideal perfection in symmetry of form and smoothness of surface are never fully realized. Further, many species usually occur not in distinct crystals, but in massive form, and in some exceptional cases the definite internal structure is absent.

These terms are naturally used to denote the different states in which a crystalline substance may appear. If a crystal is combined with a liquid, or the surface of a crystal faces a solid, or the external forces are such as to prevent the formation of only a portion of the crystal, it is termed *sublimed*, if it does appear it is *sublimed*.

7. Molecular Structure in General.—By definite molecular structure is meant the specific arrangement with the structural elements under the action of the forces exerted between them during the formation of the solid. Some remarks are given in a later article (p. 23 *et seq.*) in regard to the kinds of structural arrangement theoretically possible and their relation to the symmetry of the different systems and classes of crystals.

The definite internal structure is the essential character of a crystal, and the external form is one mode of the way, although in most important, in which this structure is manifested. Thus it is found that, in similar directions in a crystal, or a fragment of a crystal, have the physical characters,†

* In its original application the term crystal was applied only to crystals of quartz, which the ancient philosophers believed to be unchangeable in its atomic form. Hence the term, from *κρυσταλλος*, ice.

† This point is further discussed in the chapter devoted to Physical Properties, where it is established that, with some exceptions, but not in the present chapter, the converse of this proposition is true, viz., that unlike directions in a crystal have in general unlike properties.

as of elasticity, cohesion, action on light, etc. This is clearly shown by the cleavage, or natural tendency to fracture in certain directions, yielding more or less smooth surfaces—as the cubic cleavage of galena or the rhombohedral cleavage of calcite. It is evident therefore that a small crystal differs from a large one only in size, and that a fragment of a crystal is itself essentially a crystal in all its physical reactions, though showing no crystalline faces.

Further, the external form without the corresponding molecular structure does not make a crystal of a solid. A model of glass or wood is obviously not a crystal, though having its external form, because there is no relation between form and structure. Also, in connection of malachite, having the form of the crystal of cuprite from which it has been derived by chemical alteration, is not a crystal of malachite, but what is known as a pseudomorph (see Art. 491 of malachite after cuprite).

In the other hand, if the natural external faces are wanting the solid is not called a crystal. A cleavage or absorption of barite and a cleavage rhombohedron of calcite are not properly crystals, because the surfaces have been yielded by fracture and not by the natural molecular growth of the crystal.

8. Crystalline and Amorphous.—When a material shows no external crystalline form it is said to be amorphous. It may, however, have a definite molecular structure and then it is said to be crystalline. If minerals are as shown by the cleavage or by optical means, in the same in all natural crystals, then though they are not described as a definite crystal, it is said that they are grain to grain, or fiber to fiber, it is said to be a crystalline aggregate,* since it is in fact made up of a great pile of individuals.

Thus in a granular mass of minerals each may be possible to separate the fragments from each other, each with its characteristic cubic or rhombohedral cleavage. However the individuals are so small that they cannot be separated with the cleavage, and hence the crystalline structure may be evident from the springing of a freshly broken surface, as with fine-grained silicate minerals. Or, again, the aggregate structure may be so fine that the crystalline structure can only be resolved by optical methods with the aid of the microscope. In all these cases, the structure is said to be crystalline.

Statistical study has shown that more than 98 per cent of minerals show definite crystalline structure.

If optical means show a more or less distinct crystalline structure, which, however, cannot be resolved into individuals, it is said to be *crypto-crystalline*. This is true of some massive varieties of quartz.

If the definite molecular structure is entirely wanting and all directions in the mass are equally the same, the substance is said to be *amorphous*. This is true of a piece of glass, and nearly so of opal. The amorphous state is rare among minerals.

A piece of talc which has been fused and cooled suddenly may be in the glass-like amorphous condition as regards its external appearance. If even in such cases there is a tendency to grow in the direction of the lines of rearrangement, a rearrangement or change of atomic structure, both formed or fused, because opaque and crystalline after a time.

* The consideration of the various forms of crystalline aggregates is postponed to the end of the present chapter.

The microscopic study of rocks reveals many cases in which an analogous change in molecular structure has taken place in a solid mass, as caused, for example, by great pressure.

9. External Form.—A crystal is bounded by smooth plane surfaces, called faces or planes,* showing in their arrangement a certain characteristic symmetry and related to each other by definite mathematical laws.

Thus, without inquiring, at the moment, into the exact meaning of the term symmetry as applied to crystals, and the kinds of symmetry possible, which will be explained in detail later, it is apparent that the accompanying figures, 1-3 show the external form spoken of. They represent, therefore, certain definite types.



Galena



Vesuvianite



Chrysothite

10. Variation of Form and Surface.—Actual crystals deviate, within certain limits, from the ideal forms.

First, there may be variation in the size of like faces, thus producing what are defined later as *distorted forms*. In the second place, the faces are rarely absolutely smooth and brilliant, commonly they lack perfect polish, and they may even be rough or more or less covered with fine parallel lines (called striations), or show minute elevations, depressions or other peculiarities. Both the above subjects are discussed in detail in another place.

It may be noted in passing that the characters of natural faces, just as used to, in general make it easy to distinguish between them and a face artificially ground on the one hand, like the facet of a cut gem, or, on the other hand, the splintery uneven surface commonly yielded by cleavage.

11. Constancy of the Interfacial Angles in the Same Species.—The angles of inclination between like faces on the crystals of any species are essentially constant wherever they are found, and whether products of nature or of the laboratory. These angles, therefore, form one of the important distinguishing characters of a species.

Thus, in Fig. 4, of apatite, the angle between the adjacent faces α and m ($130^\circ 18'$) is the same for any two like faces, similarly situated with reference to each other. Further, this angle is constant for the species no matter what the size of the crystal may be or from what locality it may come. Moreover, the angles between all the faces on

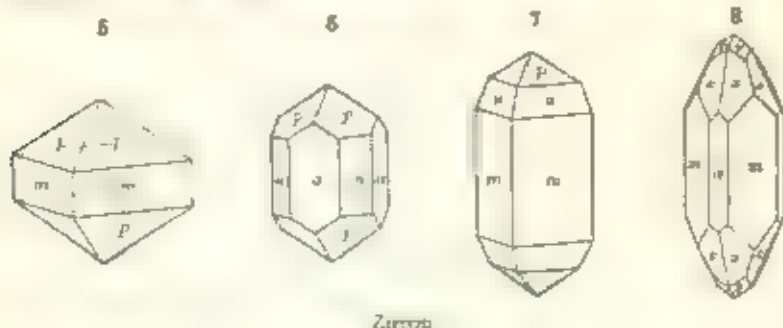


Apatite

* This latter word is usually limited to cases where the direction, rather than the definite surface itself, is designated.

crystals of the same species (cf. Figs 5-8 of zinc below) are more or less closely connected by certain definite mathematical laws.

12. Diversity of Form, or Habit. While in the crystals of a given species there is constancy of angle between like faces, the forms of the crystals may be exceedingly diverse. The accompanying figures 5-8 are examples of a few of the forms of the species zinc. There is hardly any limit to the number of faces which may occur, and as their relative size changes, the *habit*, as it is called, may vary indefinitely. The variation in crystal habit of a given species is undoubtedly due to significant variations in the conditions under which it crystallized. It has been proved experimentally that even foreign material present in the crystallizing solution can affect the habit of the crystals formed. For instance, lead nitrate will crystallize in a rhombohedral form in a pure water solution but when the solution is saturated with methylene-blue the crystals will have a cubic habit.



Zinc

13. Diversity of Size. Crystals occur of all sizes, from the inmost microscopic point to a yard or more in diameter. It is important to understand, however, that in a mature crystal, the development is as complete as with a large one. Indeed, the highest perfection of form and transparency is found only in crystals of small size.

A single crystal of quartz from Milan is 33 feet long and 54 in circumference, and it is worth noting that a single crystal of quartz from the Teton Co. is 10 feet long and 10 feet in circumference. In the collection of crystals at the University of Chicago, there is a single crystal of quartz from the Teton Co. which is 10 feet long and 10 feet in circumference. The largest crystal of quartz ever found was a single crystal of quartz from the Teton Co. which is 10 feet long and 10 feet in circumference. The largest crystal of quartz ever found was a single crystal of quartz from the Teton Co. which is 10 feet long and 10 feet in circumference.

14. Symmetry in General. — The faces of a crystal are arranged according to certain laws of symmetry, and this symmetry is the natural basis of the division of crystals into systems and classes. The symmetry may be defined in relation to (1) a *plane of symmetry*, (2) an *axis of symmetry*, and (3) a *center of symmetry*.

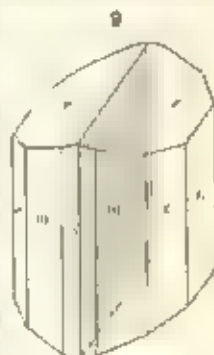
These different kinds of symmetry may or may not be combined in the same crystal. It will be shown later that there is one class the crystals of which have neither center of axis nor plane of symmetry, and in which there is only a center of symmetry. On the other hand, some classes have all these elements of symmetry represented.

15. Planes of Symmetry—A solid is said to be geometrically* symmetrical with reference to a plane of symmetry when for each face, edge, or solid angle there is another similar face, edge, or angle which has a like position to the opposite side of this plane. Thus it is obvious that the crystal of amphibole, shown in Fig. 9, is symmetrical with reference to the central plane of symmetry indicated by the shading.

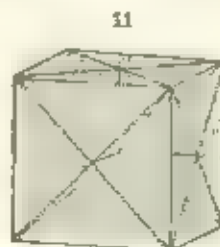
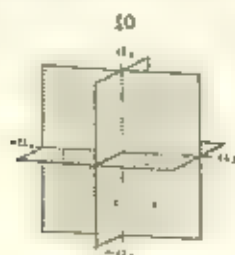
In the ideal crystal this symmetry is *right symmetry* in the geometrical sense where every point on one side of the plane of symmetry has a corresponding point at equal distances on the other side, measured on a line normal to it. In other words in the ideal geometrical symmetry, one half of the crystal is the exact *mirror-image* of the other half.

A crystal may have as many as nine planes of symmetry three of one set and six of another, as is illustrated by the cube (Fig. 16). Here the planes of the first set pass through the crystal parallel to the cubic faces; they are shown in Fig. 10. The planes of the second set join the opposite cubic edges, they are shown in Fig. 11. A plane of symmetry is always a possible crystal face and its normal is always parallel to a possible intersection between two crystal faces.

16. Axes of Symmetry If a solid can be revolved through a certain number of degrees about some line as an axis, with the result that it again occupies precisely the same position in space as at first, that axis is said to be an axis of symmetry. There are four different kinds of axes of symmetry among crystals, they are defined according to the number of times which the crystal repeats itself in appearance during a complete revolution of 360°. An axis of symmetry is always normal to a possible crystal face and parallel to the edge of intersection of two crystal faces.



Amphibole



Symmetry Planes in the Cube

(a) A crystal is said to have an axis of *binary*, *diponal*, or *twofold* symmetry when a revolution of 180° produces the result named above. In other words, when it occupies the same position twice in a complete revolution. This is true of the crystal shown in Fig. 12 with respect to the vertical axis and indeed each of the horizontal axes also.

* The relation between the ideal geometrical symmetry and the actual crystallographic symmetry is discussed in Art. 18.

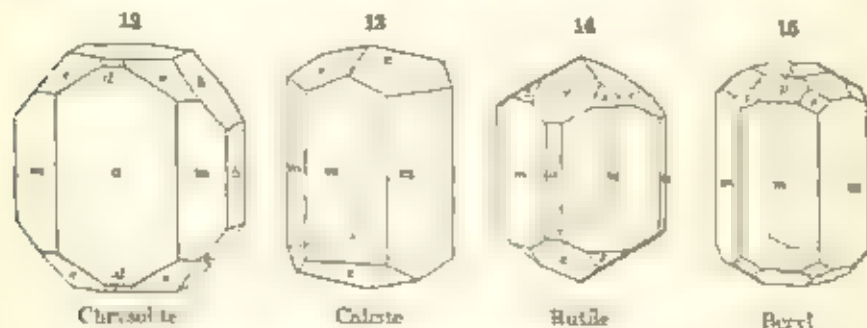
† This is the case of the normal cases of the symmetric system.

(b) A crystal has an axis of *trigonal*, or *threefold* symmetry when a revolution of 120° is needed, that is when it occupies the same position three times in a complete revolution. The vertical axis of the crystal shown in Fig. 13 is an axis of trigonal symmetry.

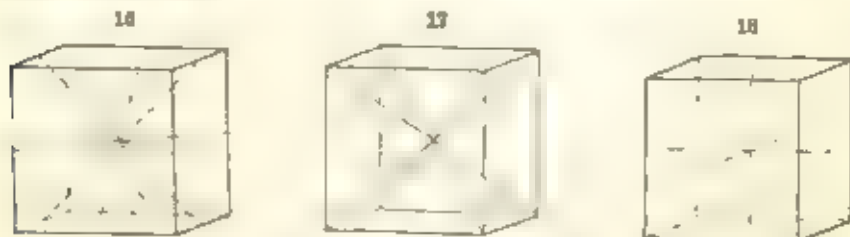
(c) A crystal has an axis of *tetragonal* or *fourfold* symmetry when a revolution of 90° is called for, in other words, when it occupies the same position four times in a complete revolution. The vertical axis in the crystal shown in Fig. 14 is such an axis.

(d) Finally a crystal has an axis of *hexagonal* or *sixfold* symmetry when a revolution of 60° is called for, in other words when it occupies the same position six times in a complete revolution. This is illustrated by Fig. 15.

A symmetry axis which also forms the line of intersection of two or more symmetry planes is called *axis of symmetry*. It is to such an axis that we refer as *trigonal*, *tetragonal*, etc. The different axes of symmetry axes are sometimes shown as *diad*, *triad*, *tetrad* and *hexad* axes.



The cube* illustrates three of the four possible kinds of symmetry with respect to axes of symmetry. It has six axes of binary symmetry putting the middle points of opposite edges (Fig. 17). It has four axes of trigonal symmetry passing the opposite ends of angles (Fig. 18). It has, finally, three axes of tetragonal symmetry putting the middle points of opposite faces (Fig. 19).



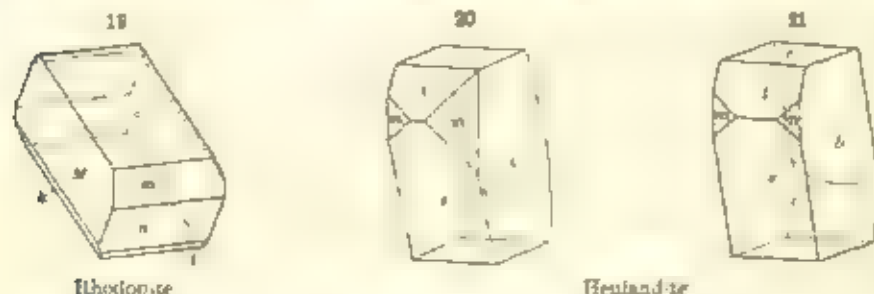
Symmetry Axes in the Cube

An axis of symmetry is termed an *alternating* axis when the faces at one end of the crystal can be obtained from the faces at the opposite end by a revolution about the axis through a certain angle and a simultaneous reflection across the plane normal to the axis. In Fig. 18 the vertical direction is such an axis of alternating symmetry; the faces at the opposite

* This is upon the cube of the normal class of the triclinic system.

small of the crystal having such positions that one set can be derived from the other only by a rotation about the vertical direction of 90° and a reflection across the horizontal plane.

17. Center of Symmetry — Most crystals, besides planes and axes of symmetry, have also a center of symmetry. On the other hand, a crystal, though possessing neither plane nor axis of symmetry may yet be symmetrical with reference to a point, its center. This last is true of the triclinic



Rhombohedr.

Hexahedr.

crystals, shown in Fig. 19 in which it follows that every face, edge, and solid angle has a face, edge, and angle similar to it in the opposite half of the crystal. In other words, a crystal has a center of symmetry if an imaginary line is passed from some point on its surface through its center, and a similar point is found on the line at an equal distance beyond the center. Another way of expressing such symmetry is to imagine the crystal turned about an axis for 60° or 180° and a simultaneous reflection of the faces over a plane normal to the axis of rotation.

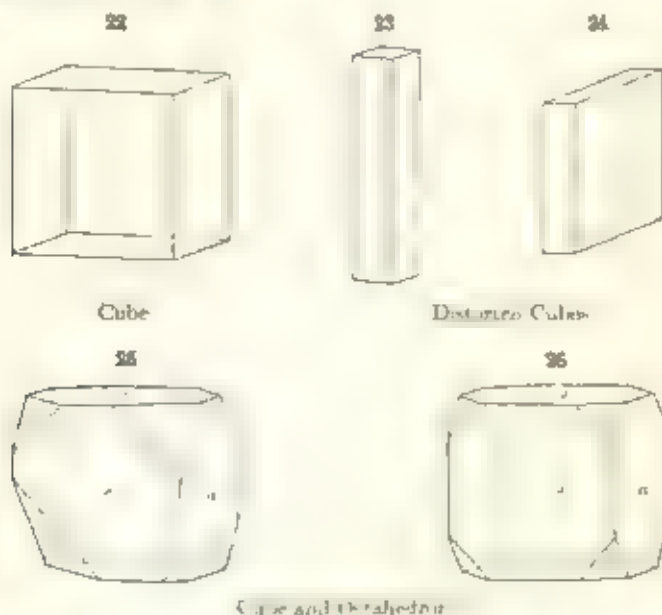
18. Relation of Geometrical to Crystallographic Symmetry — Since the symmetry in the arrangement of the faces of a crystal is an expression of the internal structure, which in general is alike in all parallel directions, the relative size of the faces and their distance from the plane or axis of symmetry are of no moment, their angular position alone is essential. The crystal represented in Fig. 20, although its faces show an unequal development, has in the crystallographic sense as truly a vertical plane of symmetry parallel to the face *b* as the evenly developed crystal shown in Fig. 21. The strict geometrical definition of symmetry would, however, apply only to the second crystal.*

Also in a normal cube (Fig. 22) the three central planes parallel to each pair of cubic faces are like planes of symmetry, as stated in Art. 15. But a crystal is still crystallographically a cube, though deviating widely from the requirements of the strict geometrical definition, as shown in Figs. 23-24, if only it can be proved, e.g., by cleavage, by the physical nature of the faces, or by optical means, that the three pairs of faces are like faces, independently of their size, or, in other words, that the molecular structure is the same in the three directions normal to them.

Further, in the case of a normal cube, a face of an octahedron on any solid

* It is to be noted that the perspective figures of crystals equally show the geometrically plane form in which the faces, edges, and angles have the same shape, size, and position. In other words, the ideal crystals are uniformly represented as having the symmetry caused for by the strict geometrical definition.

angle requires, as explained beyond, similar faces on the other angles. It is not necessary, however, that the eight faces should be of equal size for in the crystallographic sense (Fig. 23) it is as truly symmetrical with reference to the planes named as Fig. 26.



19. On the other hand, the molecular and hence the crystallographic symmetry is not always that which the geometrical form would suggest. Thus, determining for the present the consideration of pseudo-symmetry, an illustration of the fact stated is afforded by the case. It has already been pointed out that we can explain later why which is outside of the normal case of the isometric system has the symmetry described in Arts. 15, 16, a cube of the same geometrical form but being right rhombohedral, for example, to the rhombohedral case has a plane of symmetry parallel to the faces that only the six diagonal planes, for but through the four axes shown in Fig. 17 are said axes forming a symmetry (the σ axes, Fig. 18) are axes of binary symmetry only, and there are no axes of symmetry corresponding to those represented in Fig. 16. Other non-isometric cases will be described later.

Further, a crystal having a tetrahedral angles of 90° is not necessarily a cube in that while the angles between the faces do not show in this case whether the figure is bounded by six like faces, or whether only four are like and the other pair unlike, or finally whether there are three pairs of unlike faces. The question can be raised in such cases, by the molecular structure as indicated by the physical nature of the substance, by the cleavage, or by other physical characteristics as pyroelectricity, base conducted with light phenomena, etc.

Still again, the student will learn later that the decision reached in regard to the symmetry to which a crystal belongs, is based upon the distribution of the

thirteen or fourteen others are distinctly represented, though several of these are of rare occurrence. The remaining classes with possibly one or two exceptions are known among the crystallized salts made in the laboratory. The characters of each of the thirty-two classes are given under the discussion of the several crystal systems.

22. Crystallographic Axes. In the description of a crystal especially in regard to the position of its faces, it is found convenient to assume, after the methods of analytical geometry, certain lines passing through the center of the ideal crystal as a basis of reference. (See further Art. 39 *et seq.*)

These lines are called the *crystallographic axes*. Their direction is to a greater or less extent fixed by the symmetry of the crystals. For an axis of symmetry is in almost all cases* a possible crystallographic axis. Further, the unit lengths assigned to these axes are fixed sometimes by the symmetry, sometimes by the position of the faces assumed as fundamental or the unit forms in the sense defined later. The bracket lines shown in Fig. 18 are the crystallographic axes to which the cubic faces are referred.

23. Systems of Crystallization and Symmetry Classes.—The thirty-two possible crystal classes which are distinguished from one another by their symmetry are classified in the book under six systems. Each one of the six systems embraces several classes differing among themselves in their symmetry. One of these classes is conventionally classed the *normal* class since it is in general the center of one and since further extension the highest degree of symmetry possible for the given system, while the others are lower in grade of symmetry.

It is important to note that the classes comprised within a given system are at once set apart together by the characteristic properties, and are generally separated from those of the other systems in the same way.

Below is given a list of the six systems together with their subordinate classes, thirty-two in all. The order of the names given here are those that are used in this book while in the following parentheses are given other equivalent names that are also in common use. Under many of the classes it is possible to give the names of minerals or other artificial compounds whose crystals serve to illustrate the characters of that particular class. There is some slight variation between different authors in the order in which the crystal systems and classes are considered, but in the main essentials all modern discussions of crystallography are uniform.

ISOMETRIC SYSTEM

(Regular, Cubic System)

1. **NORMAL CLASS.** (Hexahedral, Holohedral, Ditetrahedral Central) {Oh. Or. Rh. Td.} *Cubic Type.*

2. **TRYPYCNEDRAL CLASS.** (Dipyramidohexahedral, Pentagonal Rhombic-hedral, Dipyramid, Tetrahedral Central) {Th. Tr. Rh.} *7 Pyram. Type.*

* Exceptions are found in the monoclinic system where the axes must necessarily be the axes of orthogonal symmetry. (Fig. 15.) and in some instances of crystals of trigonal symmetry. (Fig. 16.)

† The axes of the tetragonal and hexagonal systems are a like in some instances unusual, but the meaning of the terms is made clear by qualifying with a character.

‡ For explanation of these initials see Art. 33.

3 TETRAHEDRAL CLASS (Hexahedral, Tetrahedral, Hemihedral, Ditesseral Polar, $\{1d, 1e, 1\bar{d}, 1\bar{e}\}$, 8 Tetrahedrite Type)

4 PLAGIOHEDRAL CLASS (Pentagonal Icositetrahedral, Plagohedral, Hemihedral, Gyroidal, Tesseral, Holosaxal) $\{0, 0, 14, 3, 8\}$ Cuprite Type

5 TETARTOEDRAL CLASS (Tetrahedral, Pentagonal, Dodecahedral, Tesseral Polar, $\{1, 1, 12, 3, 5\}$ Udimannite Type)

TETRAGONAL SYSTEM

6 NORMAL CLASS (Ditetragonal, Dipyramidal, Holohedral, Ditetragonal Equatorial) $\{4h, 4d, 14, 20\}$ Zircon Type

7 HEMIMORPHIC CLASS (Ditetragonal, Pyramidal, Holohedral, Hemimorphic, Ditetragonal Polar) $\{4h, 4e, 14ed, 12\}$ Icosocucuminate Type

8 TRIPYRAMIDAL CLASS (Tetragonal, Dipyramidal, Pyramidal, Hemihedral, Tetragonal Equatorial, $\{4h, 4e, 14, 8\}$ Scheelite Type)

9 PYRAMIDAL-HEMIMORPHIC CLASS (Tetragonal, Pyramidal, Hemihedral, Hemimorphic, Tetragonal Polar, $\{4, 4, 14, 6\}$ Wulfenite Type)

10 SPHENOIDAL CLASS (Tetragonal, Sphenoidal, Sphenoidal Hemihedral, Disphenoidal, Sphenohedral, Ditetragonal Alternating) $\{4d, 12d, 12\}$ Chalepyrite Type

11 TRAPEZOHEDRAL CLASS (Tetragonal, Trapezohedral, Trapezohedral Hemihedral, Tetragonal Holosaxal, $\{04, 41, 14, 2, 10\}$ Nickel Sulphate Type)

12 TETARTOEDRAL CLASS (Tetragonal, Disphenoidal, Sphenoidal, Tetartohedral, Tetragonal Alternating, $\{84, 14, 4e, 17, 2\}$ Arif $2Ca(Al_2O_3 \cdot SiO_2)$ Type)

HEXAGONAL SYSTEM

A. HEXAGONAL DIVISION

13 NORMAL CLASS (Dihexagonal, Dipyramidal, Holohedral, Dihexagonal Equatorial) $\{12h, 61\}$ $\{0, 6\}$ 6 Beryl Type

14 HEMIMORPHIC CLASS (Dihexagonal, Pyramidal, Holohedral, Hemimorphic, Dihexagonal Polar) $\{6h, 6e, 12me, 4\}$ Zinc Type

15 TRIPYRAMIDAL CLASS (Hexagonal, Dipyramidal, Pyramidal, Hemihedral, Hexagonal Equatorial) $\{6h, 6e, 12, 6\}$ 2 Apatite Type

16 PYRAMIDAL-HEMIMORPHIC CLASS (Hexagonal, Pyramidal, Pyramidal Hemimorphic, Hemimorphic, Hexagonal Polar) $\{6h, 6e, 12, 6\}$ 6 Nephelite Type

17 TRAPEZOHEDRAL CLASS (Hexagonal, Trapezohedral, Trapezohedral Hemihedral, Hexagonal Holosaxal) $\{D6, 61, 12, 6, 6\}$ Quartz Type

18 TRIGONAL CLASS (Trigonal, Dipyramidal, Trigonal Hemihedral, Trigonal Equatorial) $\{12h, 6e, 12, 4\}$ Barite Type

19 TRIGONAL TETARTOEDRAL CLASS (Trigonal, Dipyramidal, Trigonal Equatorial) $\{12h, 6e, 12, 1\}$ Dimorphophosphate Type

B. TRIGONAL OR RHOMBOHEDRAL DIVISION

(Trigonal System)

20 RHOMBOHEDRAL CLASS (Trigonal scalenohedra) Hexagonal Scalenohedra Rhombohedral Hexahedral Cubohexagonal Alternaing (C3, 3C2, 3C2', 3C2'', 3C2''', 3C2''''; 6) Calcite Type.

21 RHOMBOHEDRAL HEMIHEDRIC CLASS (Trigonal Pyramidal Trigonal Bihedral Hemimorphic) Trigonal Polar (C3, 3C2, 3C2', 3C2'', 3C2''', 3C2''''; 6) Tourmaline Type.

22 RHOMBOHEDRAL CLASS (Rhombohedral Trigonal Rhombohedral Rhombohedral Tetartohedral Hexagonal Alternaing (C3, 3C2, 3C2', 3C2'', 3C2''', 3C2''''; 6) Phenacite Type.

23 TRAPEZOHEDRAL CLASS Trigonal Trapezohedral Trapezohedral Tetartohedral Trigonal Hemimorphic (C3, 3C2, 3C2', 3C2'', 3C2''', 3C2''''; 6) Quartz Type.

24 TRIGONAL TETARTOHEDRAL HEMIHEDRIC CLASS (Trigonal Pyramidal Trigonal Polar (C3, 3C2, 3C2', 3C2'', 3C2''', 3C2''''; 6) Sodium Periodate Type.

ORTHORHOMBIC SYSTEM

(Rhombic or Prismatic System)

25 NORMAL CLASS (Orthorhombic Dipyramidal Hemihedral Dipyramidal Hemihedral) (C2, 2C2', 2C2'', 2C2''', 2C2''''; 2) Arsenic Type.

26 HEMIHEDRIC CLASS (Orthorhombic Pyramidal Dipyramidal Polar) (C2, 2C2', 2C2'', 2C2''', 2C2''''; 2) Ima Type.

27 SYMMETRICAL CLASS (Orthorhombic Dipyramidal Dipyramidal Hemihedral) (C2, 2C2', 2C2'', 2C2''', 2C2''''; 2) Sphenoid Type.

MONOCLINIC SYSTEM

(Oblique or Monosymmetrical System)

28 NORMAL CLASS (Monoclinic Hemihedral Dipyramidal Hemihedral) (C2, 2C2', 2C2'', 2C2''', 2C2''''; 2) Gypsum Type.

29 HEMIHEDRIC CLASS (Monoclinic Pyramidal Dipyramidal Polar) (C2, 2C2', 2C2'', 2C2''', 2C2''''; 2) Tartaric Acid Type.

30 CLINOHEDRAL CLASS (Monoclinic Hemihedral Polar) (C2, 2C2', 2C2'', 2C2''', 2C2''''; 2) Clinohedrite Type.

TRICLINIC SYSTEM

(Anorthic System)

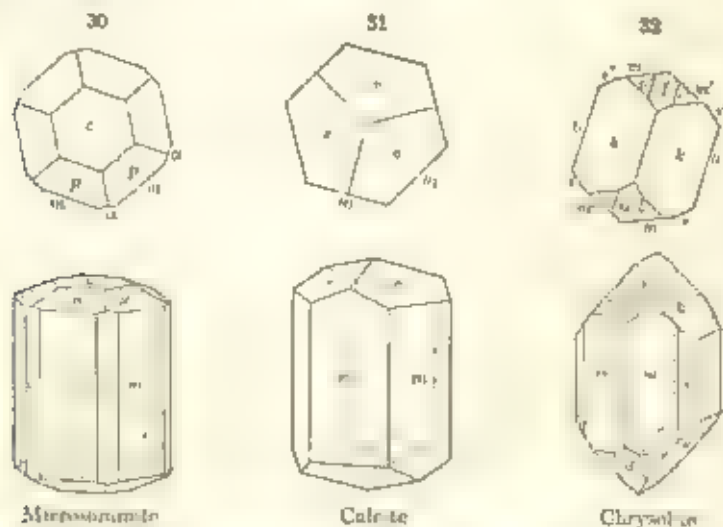
31 NORMAL CLASS (Triclinic Prismatic Central) (C1, C1', C1'', C1'''; 1) Axinite Type.

32 ASYMMETRICAL CLASS (Triclinic Prismatic) (C1, C1', C1'', C1'''; 1) Calcium Thiosulphate Type.

33. Systems of Crystallization; Crystal Axes and Symmetry In the paragraphs immediately following a statement is given describing the crystallographic axes of each of the crystal systems. It is also a synopsis of the symmetry of the normal class of each of the different systems. The symmetry is

III. Hexagonal System. Four crystal axes, three of which are equal and lie in the horizontal plane making angles of 60° and 120° with each other, while the fourth axis is vertical and has a length different, longer or shorter, from that of the horizontal axes. In the *Hexagonal Division* there are four axial planes of symmetry, of these three are horizontal planes meeting at angles of 60° , their intersection line being the vertical crystallographic axis, the fourth plane (a principal plane), is at right angles to these. There are also three other diagonal planes of symmetry meeting the three of the first set in the vertical axis and making with them angles of 30° .

Further there is one principal axis of hexagonal symmetry, this is the vertical crystallographic axis, at right angles to it there are also six binary axes. The last are in two sets of three each. Fig. 30 shows a typical hexagonal crystal with a basal projection of the same. See also Fig. 37 and Figs. 238-245.



In the *Trigonal or Rhombohedral Division* of this system there are three like planes of symmetry intersecting at angles of 60° in the vertical axis. Further, the forms belonging here have a vertical principal axis of trigonal symmetry, and three horizontal axes of binary symmetry coinciding with the horizontal crystallographic axes. Fig. 31 shows a typical rhombohedral crystal with its basal projection. See also Figs. 261-287.

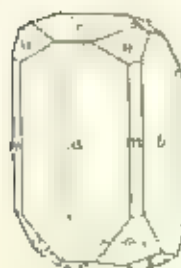
IV. Orthorhombic System. Three crystal axes at right angles to each other all of different lengths. Three vertical planes of symmetry meeting at 90° , and fixing by their intersection-lines the position of the crystallographic axes. Further, two unlike axes of binary symmetry coinciding with the last-named axes. Fig. 32 shows a typical orthorhombic crystal with its basal projection. See also Fig. 35 and Figs. 316-338.

V. Monoclinic System. Three crystal axes of unequal lengths, having one of their intersections oblique, the other two intersections being at 90° . One plane of symmetry which contains the two crystallographic axes and have the oblique intersection. Also one axis of binary symmetry, normal to

this plane and coinciding with the third crystallographic axis. See Fig. 33, also Fig. 39 and Figs. 353-367.

VI TRICLINIC SYSTEM. Three unequal crystal axes with mutually oblique intersections. No plane and no axis of symmetry, but symmetry solely with respect to the central point. Figs. 34 and 40 show typical trichlin crystals. See also Figs. 370-385.

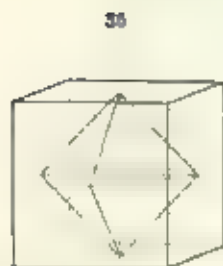
A statistical study has shown that more than one half of crystallized minerals belong to either the orthorhombic or monoclinic systems. The majority of minerals crystallize in the class of highest symmetry in the respective systems.



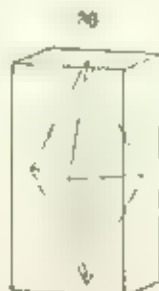
Pyroxene



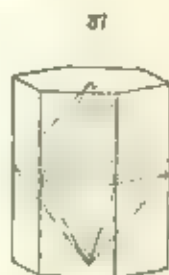
Axinite



Isometric



Tetragonal



Hexagonal

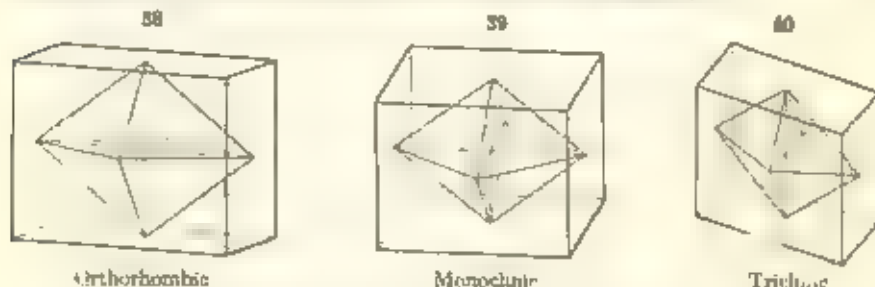
25. The relations of the normal classes of the different systems are further illustrated both regarding the crystallographic axes and symmetry by the accompanying figures, 45-49. The exterior form is here that of a crystal face, each of which is parallel to a plane through two of the crystallographic axes oriented by the central broken lines. Further, there is shown, within

thus, the combination of faces each of which joins the extremities of the unit lengths of the axes.

The full understanding of the subject will not be gained until after a study of the forms of each system in detail. Nevertheless the student will do well to make himself familiar at the outset with the fundamental relations here illustrated.

It will be shown later that the symmetry of the different classes can be most clearly and easily exhibited by the use of the different projections explained in Art. 44, *et seq*.

26. Models.—Glass for transparent cell-cast models illustrating the different systems, having the forms shown in Figs. 35-40, can be very useful, the student especially in securing his fundamental relation regarding symmetry. They should show within the crystallographic axes, and by colored threads or wires, the outlines of one or more crystal forms. Models of wood are also made in great variety and perfection of form, these are indispensable to the student in mastering the principles of crystallography.



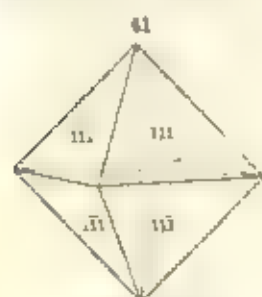
27. So-called Holohedral and Hemihedral Forms.—It will appear later that each crystal form* of the normal class in a given system embraces all the faces which have a like geometrical position with reference to the crystallographic axes, such a form is said to be *holohedral* (from *olon*, complete, and *hedra*, faces). On the other hand under the classes of lower symmetry, a certain form, while necessarily having all the faces which the symmetry allows, may yet have but *half* as many as the corresponding form of the normal class, these half-faced forms are some times called on this account *hemihedral*. Furthermore it will be seen that, in such cases, to the given holohedral form there correspond two similar and complementary hemihedral forms, called respectively positive and negative (or right and left), which together embrace all of its faces.

A single example will help to make the above statement intelligible. In the normal class of the metric system, the octahedron (Fig. 41) is a holohedral form with all the possible faces, eight in number, which are alike in that they meet the axes at equal distances. In the tetrahedral class of the same system, the forms are referred to the same crystallographic axes, as the symmetry defines in Art. 10 and more fully later, each form has but four faces having the position described. Thus come a four-faced or "hemihedral" form, the tetrahedron (Figs. 42 and 43) above the positive and negative tetrahedron, which together it will be seen, embrace all the faces of the octahedron, (Fig. 41).

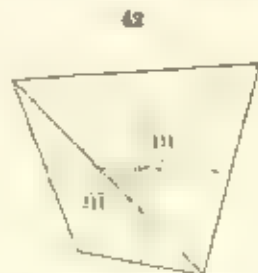
In certain classes of still lower symmetry a given crystal form may have but *one-quarter* of the faces belonging to the corresponding normal form, and, after the same method, such a form is sometimes called *tetartohedral*.

* The use of the word *form* is defined in Art. 42.

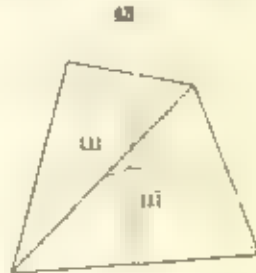
The development of the various possible kinds of hemihedral and tetrahedral forms under a given system has played a prominent part in the crystallography of the past, but it leads to much complexity and is doubtless less simple than the direct statement of the symmetry in each case. The latter method is systematically followed in this work, and the subject of hemihedrism is dismissed with the brief and incomplete statements of this and the following paragraphs.



Octahedron



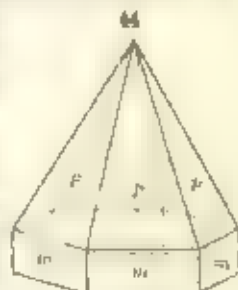
Positive Tetrahedron



Negative Tetrahedron

28. Hemimorphic Forms.—In several of the systems forms occur under the classes of lower symmetry than that of the normal class which are characterized by this, that the faces present are only those belonging to one extremity of an axis of symmetry, and crystallographic axis. Such forms are conveniently called *hemimorphic* (*half-form*). A simple example under the hexagonal system is given in Fig. 44. It is obvious that hemimorphic forms have no center of symmetry.

29. Enantiomorphic Forms.—Crystal forms are said to be *enantiomorphic* when, possessing general planes not peculiar of symmetry, they may occur in two positions which are mirror-images of each other. The two types are converted into each other by any rotation, but are related to each other as mirror-images. An example of enantiomorphism is given under the prismatic crystal class, Art. 143.

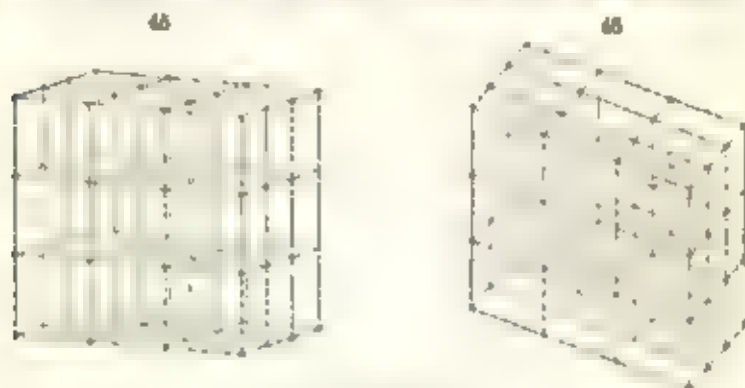


Zincite

30. Space-lattices.—Much light has recently been thrown upon the relations existing between the different types of crystals on the one hand, and of these to the physical properties of crystals on the other by the consideration of the various possible methods of grouping of the structural units of which the crystals are built. This subject, very early treated by Hanks and others, according to J. D. Dana, was discussed at length by Frankenheim and later by Bravais. More recently it has been extended and elaborated by Schenck, Wolff-Schwendler, Morawitz, Barrow, and others.

When a body passes from the state of a liquid or a gas to that of a solid, under such conditions as to allow perfectly free action to the interatomic forces, the result is a crystal of some definite type regarding symmetry. The simplest hypothesis which can be made assumes that the form of the crystal is determined by the way in which the atoms group themselves in a position of equilibrium under the action of the interatomic forces.

As, however, the crystallizing forces vary in magnitude and direction from one type of crystal to another, the resultant grouping of the crystal units must also vary, particularly regarding the distance between them and the angles between the planes in which they lie. This may be represented by a series of geometrical diagrams, showing the hypothetical grouping of a series of points. Such points may represent the positions of the elemental atoms, or the centers of similar groups of atoms. Such an arrangement of points is named a *network*, *point-system* or a *space-lattice*. A space-lattice may be defined as a network of points arranged in such a manner that a straight line drawn through any two points and continued will pass at equal intervals through a succession of similar points and the line extension will hold true for any parallel line drawn through any other similar point.



Crystal Networks

The subject may be illustrated by Figs. 45, 46 for two typical cases, which are easily understood. In Fig. 45, the most special case is represented where the points are grouped at equal distances, in planes at right angles to each other. The structure in this case obviously corresponds in symmetry to the case described in Arts. 16 and 18, or, in other words, to the normal class of the isometric system. Again in Fig. 46, the general case is shown where the molecules are unequally grouped in the three directions, and further these directions are oblique. The symmetry is here that of the normal class of the triclinic system.

If, in each of these cases, the figure be bounded by the simplest possible arrangement of eight points, the result is an *elementary parallelepiped*, which obviously defines the structure of the whole. If the grouping of these parallelepipeds together as described it is obvious that in whatever direction a line be drawn through them, the points will be spaced alike along it, and the grouping at any one of these points will be the same as about any other.

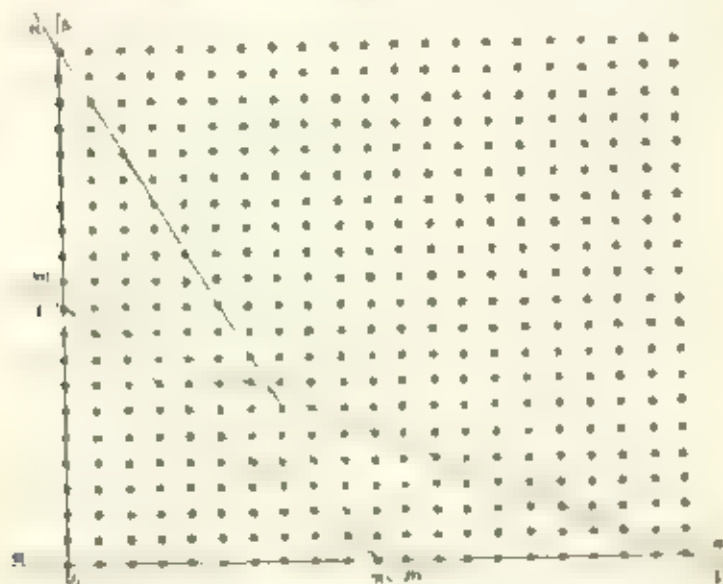
31. Certain important conclusions can be deduced from a consideration of such regular molecular networks as have been spoken of, which will be enumerated here though it is impossible to attempt a full explanation.

(1) The prominent crystal faces must be such as include the largest number of points, that is, those in which the points are nearest together.

Then in Fig. 47, which represents a section of a network conforming in symmetry to the structure of a normal or non-normal crystal, the common

crystalline faces would be expected to be those having the position bb , aa , mm , then ll , nn , and so on. This is found to be true in the study of crystals, for the common forms are in nearly all cases, those whose position bears some simple relation to the assumed axes, forms whose position is complex are usually present only as small faces on the simple predominating forms, that is as modifications of them. So-called *actual* forms, that is, forms taking the place of the simple fundamental forms to which they approximate very closely in angular position, are exceptional.

47

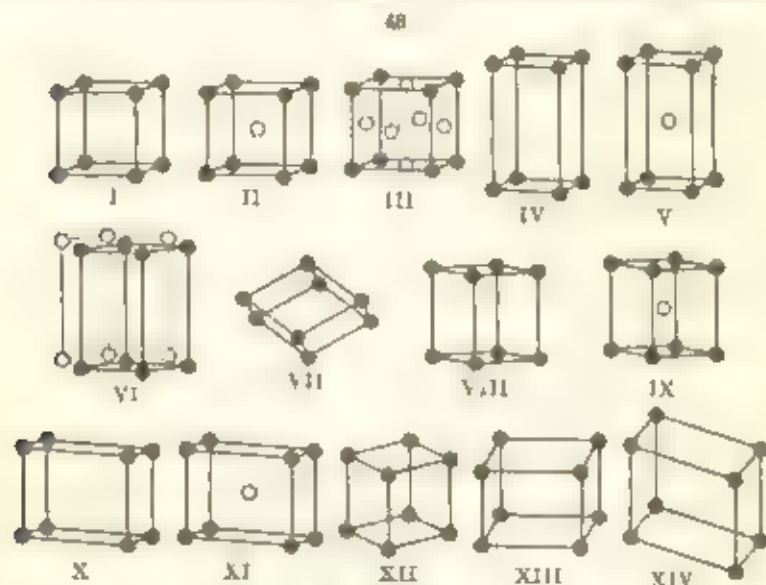


Orthorhombic Point System

(2) When a variety of faces occur on the same crystal, the numerical relation existing between them, that which fixes their position, must be rational and constant. In the simple numerical ratios to be expected in the common cases. (This, as explained later, is found) by experience to be a fundamental law of crystals. Thus, in Fig. 47, starting with a face meeting the section in mm , ll would be a certain face, and for nn in ratio of 1 : 2 in the directions b and a , nn would be also common with the ratio 2 : 1.

(3) If a crystal shows the natural easy fracture, called cleavage, due to a minimum of cohesion, the cleavage surface must be a surface of relatively great molecular crowding, that is one of the common or fundamental faces. This follows, and it gives a partial, though not complete, explanation of cleavage, since it admits of easy proof, that that plane on which the points are closest together is furthest separated from the next unequal plane. Thus in Fig. 47, to repeat the distances separating two adjacent faces parallel to bb or aa , then two parallel to mm , ll , nn , etc. If sections of the above will be found under the special discussion of the subject of cleavage.

32. Kinds of Space-lattices.—A theoretical study of the arrangements of points in space such that the conditions stated above under the definition of a space-lattice would be fulfilled showed that there were possible only fourteen such networks. These agree as to their symmetry with the seven classes defined in Art. 24 as representing respectively the various classes of the six systems with also that of the trigonal (or the rhombohedral) division of the hexagonal system. Of the fourteen, three groupings belong to the isometric system, two to the tetragonal, one each to the hexagonal and the rhombohedral, four to the orthorhombic system, two to the monoclinic, and one to the triclinic. These fourteen different lattices are represented in Fig. 18. I represents the simple cubic lattice. II the body-centered cubic lattice



Space lattices

which consists of two cubic lattices interpenetrating in such a way that the points of the second lattice lie at the centers of the unit cells of the first lattice, III, the face-centered cubic lattice in which four cubic lattices interpenetrate; IV, the tetragonal or square prism lattice; V, the body-centered tetragonal or square prism lattice; VI, the hexagonal prism lattice, three of whose unit cells together form the hexagonal prism; VII, the rhombohedral lattice; VIII, the orthorhombic prism lattice; IX, the body-centered orthorhombic prism lattice; X, the rectangular parallelepiped lattice; XI, the body-centered rectangular parallelepiped lattice; XII, the monoclinic parallelepiped lattice; XIII, the monoclinic parallelepiped lattice; XIV, the triclinic lattice.

33. Space-groups or Point-systems.—It will be noted that the fourteen space-lattices described above will yield only the normal or hexahedral classes of the various systems. They cannot therefore account for the classes of lower symmetry. It is necessary to extend the theory in order to include these other classes. The points of a given space-lattice represent the struc-

third units of a crystal usually described as its *facets*, a group of molecules and it is this structure that governs the crystal system, the next question. But the space lattice of crystals does not necessarily follow this symmetry class. If however the positions of the individual atoms of the crystal are considered, other data may, but do not refer to the symmetry of a crystal. The one given above, can be formulated that with accuracy for all possible symmetry classes. Schenke showed that by assuming with consideration to the symmetry of the crystal system, a group of points could be derived from another by some definite arrangement of axes, or *point systems* could be derived. The various *point systems* corresponding to various, by which one set of points can be derived from another are of various kinds. The sixty five point systems of Schenke may be classified by assuming arguments: 1) through a definite direction in space definite direction; 2) by a rotation of a given number of degrees about a definite axis; 3) by a combination of 1) and 2) in which there is a rotation about some axis accompanied by a movement along the direction of the axis, such an axis is commonly called a *rotation axis*. These sixty five point systems are not for all but eleven of the thirty two symmetry classes. The missing classes are those that show enantiomorphic forms, or in other words those forms that have right and left-handed relations to each other. It is not necessary for these cases the necessity to assume that we may have two interpenetrating point systems composed of different types of particles which have such characters that they show enantiomorphic relations to each other. These two interpenetrating point systems are to be derived from each other by movements which may be further defined, such as a rotation over a point, a reflection over a plane, a translation by a vector, a rotation of a definite angle and direction in a certain plane with reflection over a plane normal to the axis of rotation about a center of symmetry. By using such methods of derivation, Schenke, H. F. Schenke and H. F. Schenke independently and almost simultaneously between 1901 and 1904 extended the theory of point systems and it is evident that there were many wonderful and thirty possible types of homographic symmetry. If all these groups be considered, but the are a group of thirty two symmetry classes, point systems, but each possesses a characteristic similarity. These have on the basis of the theory of point systems defined a crystal as follows: a crystal is a solid body in which the molecules are arranged in a repeating regular point system, each of which is formed from equivalent points, each of these point systems is built up from an interpenetrating space lattice, each of the latter being formed from molecules at the repeating points. All the symmetries of the crystal and the symmetries are given in many directions or are characterized by the same mathematical, periodicity.

These two hundred and thirty types of structure can all be grouped under the thirty two symmetry classes of crystals. From the point of view of the general crystallographer they are of only theoretical interest, but for the investigation of the atomic structure of crystals by use of the X-ray method they are of the utmost practical importance. A complete explanation of their characters and relations are given in the comprehensive and extended treatment of the subject here. In the main Art. 23 in which are listed the thirty two symmetry classes of crystals the point-group symbols of these classes are given in brackets. The first symbol is that used by Schoenflies

the second, the symbol proposed by Hutton and modified by Wyckoff; the third the symbol adopted by an international conference held at Zurich, August 1930. The numbers following these symbols in the brackets show how many different space-groups occur in the various symmetry classes. The particular space-group in question is indicated by using the proper exponent to modify the group symbol. For instance, the fourth space-group under the normal class of the rhombohedral system would be given the symbol $R\bar{3}c$ or $R\bar{3}c/4$.

The following books either concern themselves wholly with the theory of space-groups or contain chapters giving detailed descriptions. To them the interested reader must be referred.

Hutton. *Mathematical Crystallography*, 1933.

Nagel. *Kristallographie*, 2te Aufl., 1924. *Die Kristallographie*, 1924.

Schererhold. *Über die neue Herleitung der Symmetriesterne der 230 kristallographischen*

Räume, 1934.

Schoenflies. *Kristallsysteme und Kristallstruktur*, 1901. *Theorie der Kristallstruktur*, 1923.

Sommerfeld. *Physikalische Kristallographie*, 1927.

Tutton. *Crystallography and Physical Crystallography*, Vol. I, Chapters 30, 31, 1922.

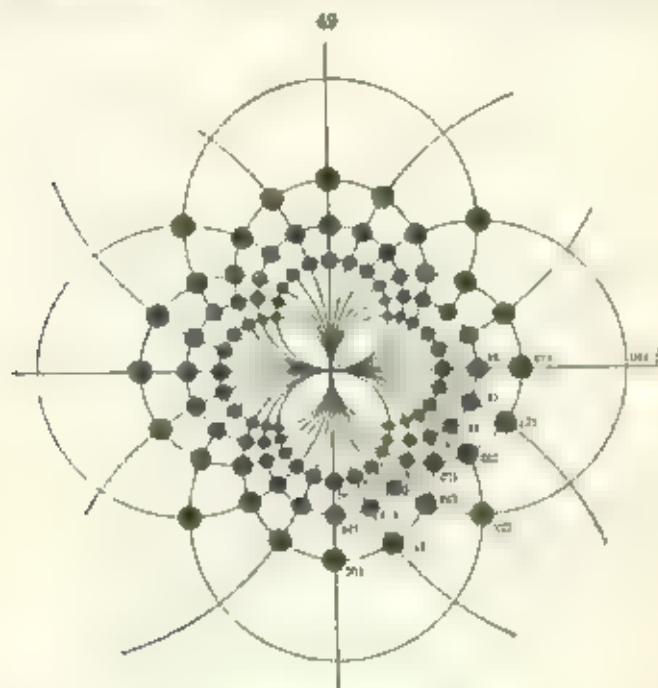
Wyckoff. *The Analytical Expression of the Results of the Theory of Space-Groups*, 1923. *Crystallography*, 1923.

In *The Elements of Crystallography*, Vol. I, p. 25, 1933 is given in tabular form a comparison of the various notations that are in use for space-groups.

34. Analysis of Crystal Structure by Means of the X-rays.—In 1912 about twenty years after the first formation of the two hundred and thirty space-groups the theory of crystal structure outlined above received a definite proof when it was discovered that a beam of X-rays would suffer reflection and refraction by the atoms of a crystal. X-rays discovered in 1895 by Roentgen are produced by the rays of an incandescent tube or cathode when they fall upon a very hard substance. The quantity and wave-length of the X-rays depend upon the material of which the cathode is made. X-rays travel outward from the point of origin in straight lines and because of their very short wave-lengths are able to penetrate all substances to a greater or less degree. Their effect upon a photographic film is that of light, certain substances fluoresce when exposed to them, and gases are ionized and become conductors of electricity when X-rays are passed through them. Physicists had come to believe that X-rays were electromagnetic vibrations similar to those of light and that shorter wave-lengths. It had been well known that the wave-length of X-rays are approximately 1,000 times shorter than those of light. Because of this short wave-length it had been possible to reflect or diffract the X-rays and so to project an image of their structure. In 1912 Dr. L. Bragg and Dr. W. L. Bragg made the suggestion that the suggested atomic structure of crystals might have definite relations to the wave-length of the X-rays and that therefore it was possible to determine the diffraction grating. And by Bragg and Dr. L. Bragg it was proved that it was true of passing a beam of X-rays through crystals the periodicity of which is comparable with their wave-length. When this was done the crystals showed a dark spot on a screen where the X-rays fell and a light spot where they were diffracted. The light spot was the direct beam of X-rays or geometric pattern. Each of these spots was due to the reflection of the

X-rays by a very large series of parallel planes in the atomic structure. By this and subsequent similar experiments Laue showed the similarity between the vibrations of X-rays and those of light and at the same time indicated a method for the precise study of the atomic structure of crystals.

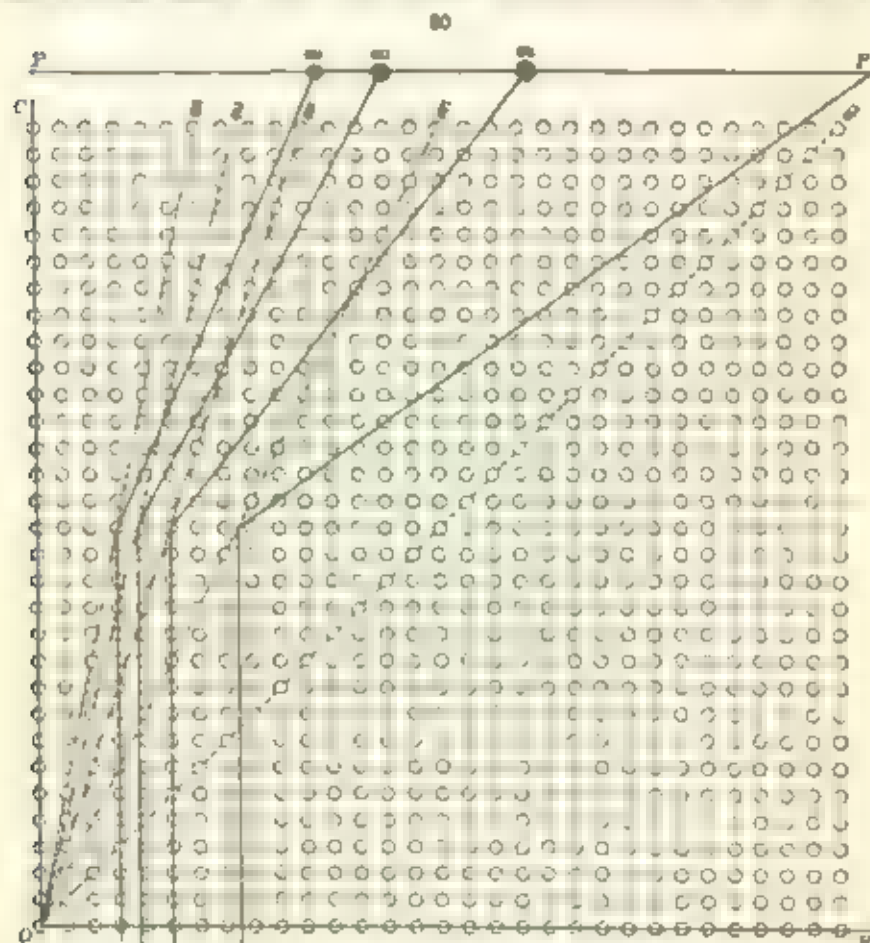
35. Laue Diffraction Patterns. In Fig. 49 is given a diagrammatic representation of the spot pattern produced when X-rays are passed through a crystal of potassium chloride, *syssite*, in a direction normal to a face of the cube. Each spot of the pattern indicates an atomic plane that corresponds to a possible crystal face. The arrangement of the spots is controlled by the symmetry of the crystal, although it should be noted that the spot patterns



Laue Diffraction Pattern for KCl

may indicate a higher symmetry than that actually possessed by the crystal. The spots vary in their intensity, and this is due to a variation in the number of atoms present in a given area of the reflecting plane or face. Variation in the reflecting power of the different kinds of atoms is to be found in the given crystal. As the commoner crystal faces are those in which the larger number of atoms lie, such planes are indicated by the larger spots. In the photograph the spots are at the intersections of ellipses, each of which passes through the center of the pattern. The spots from all planes lying in one crystal zone will be found on one ellipse. In Fig. 49 these ellipses have been reduced to circles. The central portion of the picture is void of spots. This is due to the fact that the distances between planes that give steep reflections to the path of the X-rays are less than the wave-length of the X-rays. Faces

with low inclinations are also not represented since the X-rays would be reflected at too great an angle to permit them to reach the photographic plate. Fig. 50 will aid in visualizing these facts. It shows a vertical plane through the cubic network of potassium chloride that includes the b ($O-B$) and c ($O-C$) crystal axes. The atomic planes having the indices (011) ,



X-ray Reflection in KCl

(021) , (031) , (041) , (051) are shown by the broken lines. The line $P-P$ would represent a section of the photographic plate corresponding in position to line $P-P$ in Fig. 49. The solid lines within the figure represent the paths of the X-rays before and after reflection from individual atomic planes. Reflections from (011) and (021) would not meet the photographic plate and the reflections from (041) , (041) , and (051) would show a decrease in intensity due to the decreasing numbers of atoms in the successive planes. The varia-

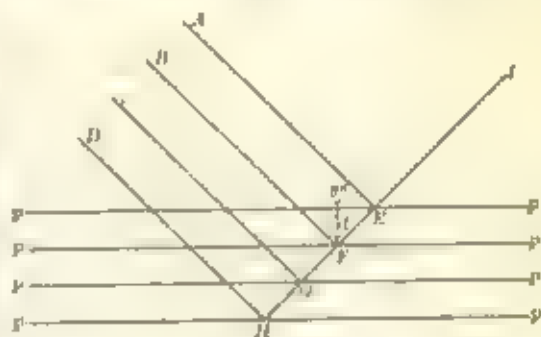
tion in intensity of the various reflections is indicated in Fig. 49, which is much realized, by variation in the size of the spots.

The spots of the Laue patterns are due to reflection of the X-rays not from a single atomic plane but from a very great number of parallel planes. It is necessary therefore that the successive reflected waves are all together in the same phase of wave motion and so be able to reinforce each other or else being in different phases they would interfere with each other and the wave motion in that particular direction would be destroyed. The law for the reflection of X-rays is given by the equation $n\lambda = 2d \sin \theta$, in which n equals some integer, λ the wave-length of the X-ray, d the distance between the parallel reflecting planes, and θ the angle between the path of the X-ray and the reflecting plane. This law is illustrated in Fig. 51 where the series of parallel X-rays *A, B, C, D*,

are reflected from the series of parallel planes *p-p* at the points *E, F, G, H* in the direction *I*. In the reflection of X-rays according to the Laue method the distance d for any given series of atomic planes is fixed and the value of θ is also definite. In order, therefore, to satisfy the equation and have reflection taking place from any atomic plane it is necessary to be able to vary the value of λ . In making the Laue patterns it is therefore necessary to use the so-called "white radiation" of X-rays which contains a spectrum of varying wave-lengths, one of which will satisfy the conditions of the equation and yield a series of reflected waves, all agreeing in phase. An anti-cathode provides some of this general radiation in addition to their own peculiar wave-length but in the case of platinum or tungsten the amount of such radiation is at a maximum and these are the metals commonly used as anti-cathodes in making Laue pictures.

Fig. 52 gives a diagrammatic representation of the Laue photograph obtained from a crystal of halite, sodium chloride. Comparison of this figure with that representing the spot photograph of potassium chloride shows marked differences. In Fig. 52 there are 16 spots at the intersections representing the planes (501), (521), (541), (561), etc. Further, the intensities of the spots do not vary in a regular manner. The explanation of these differences lies in the fact that in potassium chloride, the potassium and chlorine atoms have nearly the same atomic weights and nearly equal powers of reflection of X-rays. Consequently the structure of potassium chloride as far as X-rays are concerned can be considered to consist of only one kind of atom, as is represented in Fig. 50. In sodium chloride, on the other hand, the atomic weights of sodium and chloride are quite different and as a result they reflect the X-rays with different intensities. The structure of sodium chloride must be represented as composed of two different kinds of atoms, as shown in Fig. 53. Some of the reflecting planes would contain only atoms of one kind,

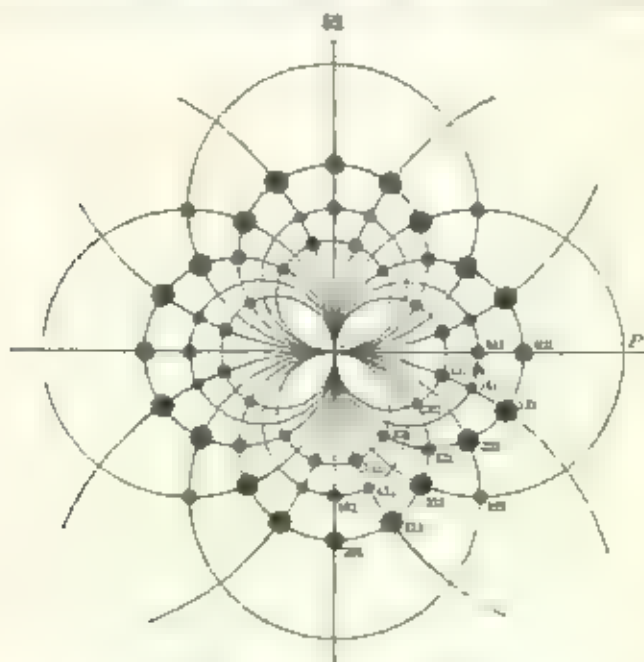
51



Reflection of X-rays

as for instance planes parallel to (011) , (031) , (051) are either all light or all dark spots in Fig. 53, while other planes (such as (121) , (041)) would show an alternating arrangement of the two elements. The series of reflecting planes, therefore, in this structure are of two different types and should show differences in their reflectivities such as are seen in Fig. 52. From these observations it is concluded that the structure of potassium chloride can be represented by the simple cubic lattice, while that of sodium chloride belongs to the face-centered cubic lattice. I and III Fig. 48.

The two Laue diagrams considered above were made normal to a principal symmetry axis of the crystal. Other pictures could be made normal

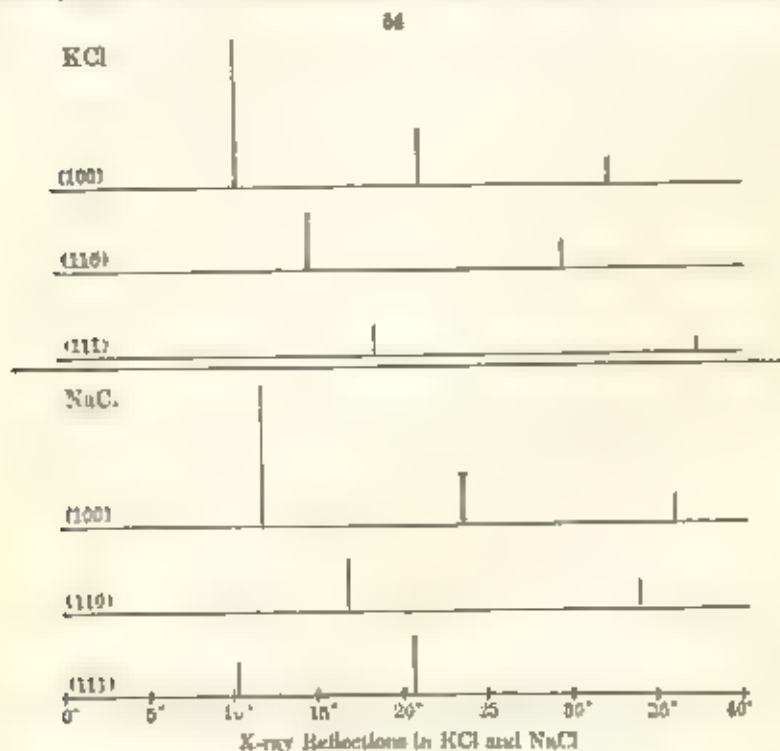


Laue Diffraction Pattern for NaCl

to other axes with corresponding differences in the patterns. Together these various patterns would enable one to learn much concerning the atomic structure of the mineral studied. To be of use the Laue pictures should have a definite and known crystal orientation.

36. The X-ray Spectrometer Other methods for using X-rays in the investigation of crystal structure were soon devised. The first of these was the X-ray spectrometer developed by W. H. Bragg and W. L. Bragg. With this instrument the crystal is mounted in a central post which can be revolved about its axis. The arrangement is closely similar to that used in mounting and measuring crystals on the ordinary reflection goniometer. In place of a beam of light a beam of X-rays is directed at the crystal. In fact one X-ray is used that in place of which one known wavelength is used. Under certain conditions the X-rays are reflected from a series of parallel

BEI joins *AEI* at *E*, they will both be in the same phase of wave motion. The same holds true, of course, for the entire series of reflected rays, each in turn differing in phase by a whole wave-length. Under any other circumstances the rays would interfere with each other and there would be no vibration along *EI*. With λ known and θ measured, it is possible to calculate from the equation the value of d , the distance between the reflecting atomic layers. A similar reflection of the beam of X-rays may take place at such other angles as to make the difference in phase between the succession of

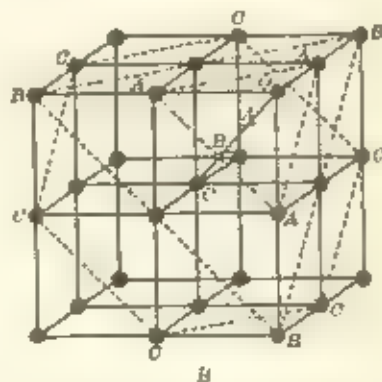
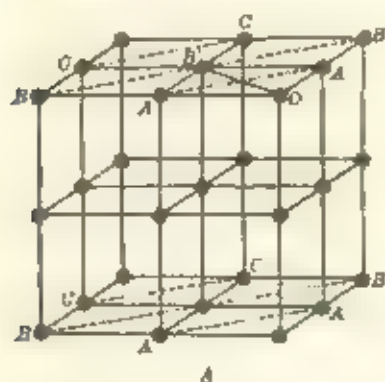


reflected rays 2, 4, 6, etc., wave-lengths, or even 3, 6, 9, etc., wave-lengths. These different reflections are known as reflections of the first, second, third, etc., orders. The orientation of the crystal planes from which the X-rays are reflected must be known. By changing the position of the crystal, the spacing and characters of the atomic layers parallel to any crystal plane may be studied.

In Fig. 54 is shown diagrammatically the result of the investigation of the potassium and sodium chlorides by the X-ray spectrometer. Reflections from the atomic planes parallel to the cube (100), dodecahedron (110), and octahedron (111), were studied, in each case. In the figure the vertical lines show the angles (2θ) at which the X-ray having the predominant wave-length of the palladium spectrum were reflected in each case, and the lengths of these lines indicate the relative intensity of the reflections. Two or three

orders of reflection are shown. From the observations with potassium chloride it was possible to calculate the value of d for the three sets of planes and it was found that the ratio was $\frac{1}{d_{100}} : \frac{1}{d_{110}} : \frac{1}{d_{111}} = 1 : \sqrt{2} : \sqrt{3}$. This ratio satisfies the conditions found in the simple cubic lattice. Fig. 55A, represents eight unit cubes of this lattice. The diagonal planes, A , B , and C

54



through this lattice are parallel to the dodecahedron plane (110). The distance d_{110} between the planes A and B is one-half the face diagonal BO of the unit cubic cell, therefore $d_{110} = \frac{d_{100}\sqrt{2}}{2}$. In Fig. 55B, the octahedral planes A , B , and C are indicated in the same cubic lattice. The planes A and B divide the body diagonal ($O-C'$) of the unit cube into thirds as indicated at the points A and B . Therefore $d_{111} = \frac{OC'}{3}$, or $\frac{d_{100}\sqrt{3}}{3}$. If we let $d_{100} = 1$, then $d_{110} = \frac{\sqrt{2}}{2}$ or $\frac{1}{\sqrt{2}}$, and $d_{111} = \frac{\sqrt{3}}{3}$ or $\frac{1}{\sqrt{3}}$. Therefore for

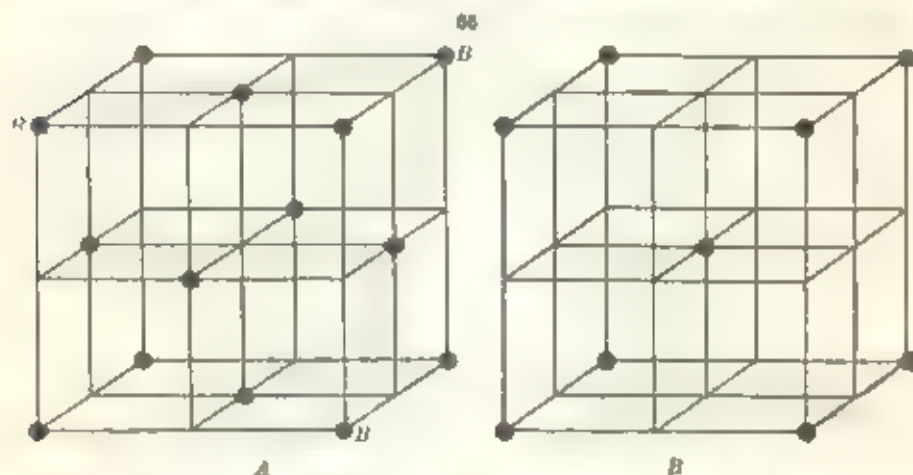
these three interatomic distances we may derive the ratio $\frac{1}{d_{100}} : \frac{1}{d_{110}} : \frac{1}{d_{111}} = 1 : \sqrt{2} : \sqrt{3}$, agreeing with the ratio obtained from the X-ray measurements. In this way it was shown that the atomic arrangement of potassium chloride was that of the simple cubic lattice.

Fig. 56A shows eight unit cells of the face-centered cubic lattice. Inspection of the figure will show that d_{100} and d_{110} are the same as in the cubic lattice. Fig. 55A. But of the octahedral planes shown in Fig. 55B, only the plane B appears in Fig. 56A, and the spacing between such planes must be twice as great as in the first case. Therefore the ratio of the three interatomic distances for the face-centered cubic lattice is $\frac{1}{d_{100}} : \frac{1}{d_{110}} : \frac{1}{d_{111}} =$

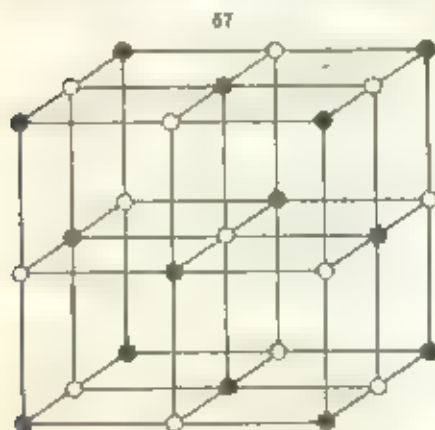
$1 : \sqrt{2} : \frac{\sqrt{3}}{2}$. Fig. 56B shows the body-centered cubic lattice and for this

the ratio will become $\frac{1}{d_{100}} : \frac{1}{d_{110}} : \frac{1}{d_{111}} = 1 : \frac{1}{\sqrt{2}} : \sqrt{2}$.

The X-ray reflections obtained from sodium chloride, indicated in the lower half of Fig. 54, show certain interesting differences from those of potassium chloride. In the case of the 100 , and 110 planes the reflections are similar but at a slightly greater angle in the case of NaCl , indicating that an



its structure the distances d_{100} and d_{110} are a little smaller than with KCl . In the case of the reflections from planes parallel to 111 where there is a reflection at an angle similar to the first reflection in the case of KCl , there is also another reflection in the case of NaCl at most of the angles. This indicates that the spacing of the octahedral planes corresponds to that of the face-centered cubic lattice instead of the cubic lattice. The first reflection from the octahedral planes in NaCl is of less intensity than the second reflection. This is contrary to the rule of regularly diminishing intensities when the reflecting planes are all of the same character. In order to account for these facts a structure for NaCl is assumed like that shown in Fig. 57 the solid dots representing atoms of sodium, while the circles indicate atoms of chlorine or vice versa. It will be noticed that the sodium and chlorine atoms considered separately are placed in face-centered cubic lattices, the two



Atom Structure of NaCl

lattices interpenetrating each other to form a simple cubic lattice. Note the planes parallel to either 100 or 110 show both Na and Cl atoms alternating with each other; therefore these two sets of planes have uniform powers of reflection. On the other hand the octahedral planes, two of which are

equally spaced to the right and left of the center of the photograph. All planes that are inclined to the axis of rotation will have their reflections lying on the surfaces of cones whose axis coincides with the axis of rotation of the crystal. Each set of reflecting planes will be represented by four spots, two above and two below the central horizontal line and equally spaced to the right and left of a central vertical line. All planes having the indices (hkl) will have their reflections lying on the same cone. This cone will intersect the plate in a flat hyperbola and the circular film in a straight line. The points from the series of (hkl) planes will be on the first line above or below the central horizontal line. Those having in lieu of (hkl) will be on the second line, etc. The spots in the picture will also have approximately a vertical arrangement over each other. If a spot on the central horizontal line is a reflection from (hkl) the spots above it on the successive lines will be $(hk1)$, $(hk2)$, etc. From the distances between the lines of $(hk0)$, $(hk1)$, etc. and the distance from the crystal to the plate or film can be calculated one dimension of the unit cell of the atomic structure. If the same crystal is rotated with other axes of rotation, data can be accumulated from which the details of the structure can be derived. Fig. 60 shows diagrammatically the spots of a rotation photograph of NaCl , a crystallographic axis being used as the axis of rotation.

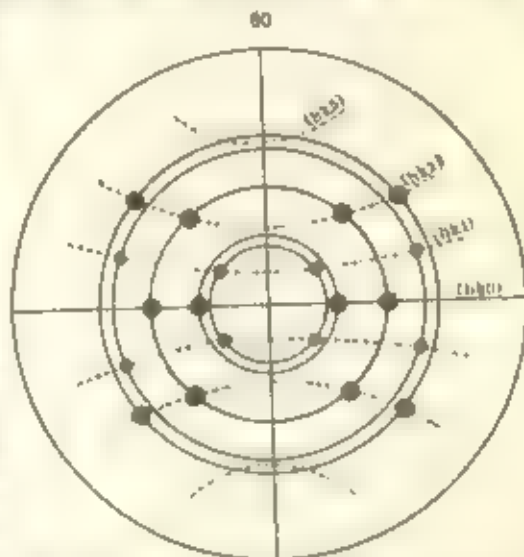


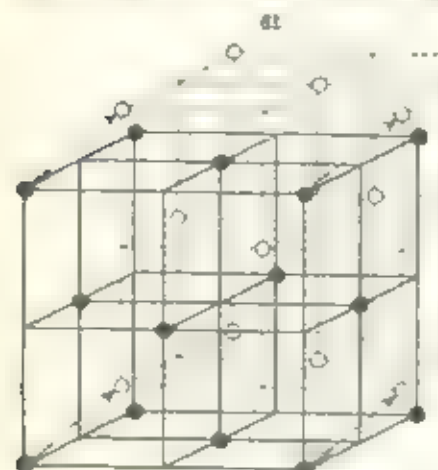
Diagram of a Rotation X-ray Photograph of NaCl
(Axis of Rotation parallel to Crystal Axis)

III. *The Oscillation Method* — This is a modification of the rotation method. Instead of turning the crystal in an axis through an angle of 360° it is turned back and forth through an angle of about 40° from a known position. A beam of X-rays with uniform wavelength is used and the spectra are recorded on a photographic plate which is placed behind the crystal, parallel to the axis of rotation and turned to the incident X-ray. The resultant photograph will be like the right or left half of a rotation photograph and the same methods of calculation are used in the two cases.

38. *Examples of Crystal Structure as Determined by the Use of X-ray Methods.* — Certain interesting examples of crystal structure that have been worked out by the use of X-rays are given below as a further illustration of the great importance of these methods. Lack of space will permit only the results of the investigations to be given.

1. *Sphalerite* — This was the mineral first examined by X-rays by Laue. Its structure is represented in Fig. 61. The solid circles might indicate the zinc atoms. They are arranged on a face-centered cubic lattice. The hollow

circles, representing sulphur atoms, lie on a similar lattice, interpenetrating the first and which, can be derived from it by a movement along the body diagonal of the cube for a distance equal to one-sixth of its length. The



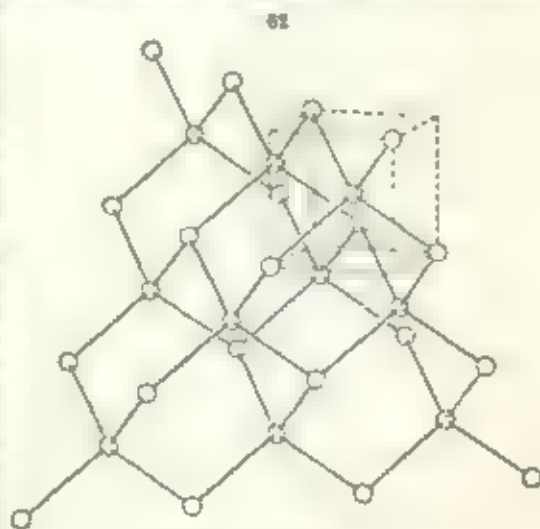
Structure of Sulphurite

direction of movement in order to derive one lattice from the other is indicated by the arrows.

2. *Diamond*—The diamond structure was also one of the earlier ones studied. The carbon atoms are arranged on two interpenetrating face-centered cubic lattices in exactly the same way as in zinc and sulphur dioxide. If we represent the lattice points by solid circles we would have an illustration of the crystal structure. Fig. 62 represents the diamond structure in a different way. The cubes shown in broken lines give the crystal orientation of the structure. If it is imagined

that this figure is infinitely extended it will be seen that the carbon atoms are at the center of a group of four other atoms, which taken together form the points of a tetrahedron. Further the carbon atoms are arranged in hexagonal rings. This is a very solid and compact atomic grouping and presumably accounts for some of the striking physical properties of the diamond.

3. *Graphite*—It is interesting to compare the structure of graphite with that of diamond. In graphite the carbon atoms are arranged in parallel layers, those of each layer forming interlocking hexagons. Fig. 63 represents the projection of one such layer. The atoms in these rings do not all lie in the same plane but are either slightly above or below the central plane. The distances between the atoms in these hexagons is even smaller than the interatomic distances in the dia-



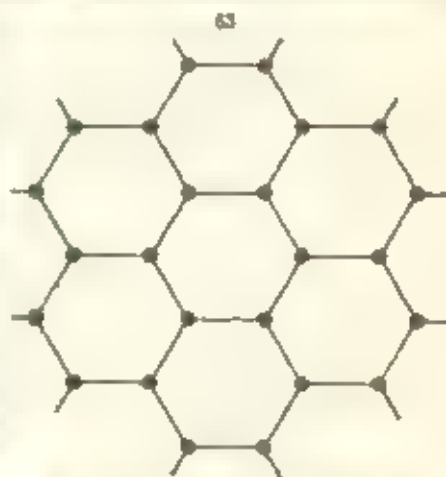
Structure of Diamond

mond structure. On the other hand the distance between successive layers is unusually large, about two and one-half times the spacing of the layer itself. The wide spacing of the layers undoubtedly accounts for the foliated structure and basal cleavage of graphite, while the close-knit structure of the individual layer accounts for the fact that graphite cannot be readily powdered but separates rather into thin flakes. This is the property which makes it such a good lubricant. It is interesting also to note that in both diamond and graphite the carbon atoms are arranged in hexagonal rings, a kind of atomic grouping long recognized as characteristic of carbon in organic compounds. Another interesting fact is that if the distances between the warped hexagonal rings of the graphite structure be shortened a structure very similar to that of the diamond can be derived.

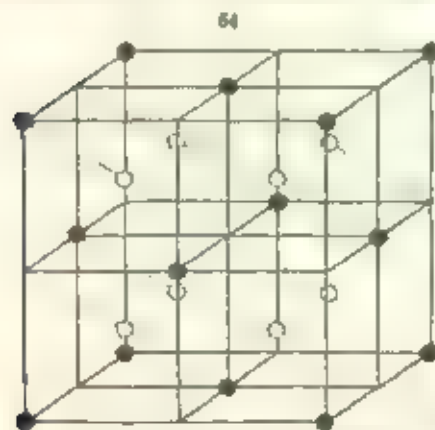
4. *Fluorite*.—Fig. 63 represents the structure of fluorite, in which the calcium atoms, i.e., the points of a face-centered cube, while the fluorine atoms lie at the centers of the eight small cubes that compose one face-centered cube.

5. *Pyrite*.—The structure of pyrite is similar to that of fluorite, the iron atoms lying on a face-centered cube lattice, but the sulphur atoms instead of lying at the center of the eight small cubes, lie on a body diagonal of each of the small cubes at a point one-fifth of the length of the diagonal from one of its ends. Fig. 64 attempts to show this arrangement. The top view shows the distribution of the atoms and clearly indicates why pyrite belongs to a crystal class of lower symmetry than fluorite.

6. *Calcite*.—Fig. 65 attempts to show the atomic arrangement of calcite. The carbon and oxygen atoms lie on interpenetrating rhombohedral lattices and their positions are analogous to those of the sodium and chlorine atoms in the structure of halite (compare Fig. 57). Except for the fact that the unit cell for calcite is a rhombohedron instead of a cube, the two structures are identical. It has been possible with only a few atoms in the structure. They are grouped in sets of three about the carbon atoms and they all lie in the



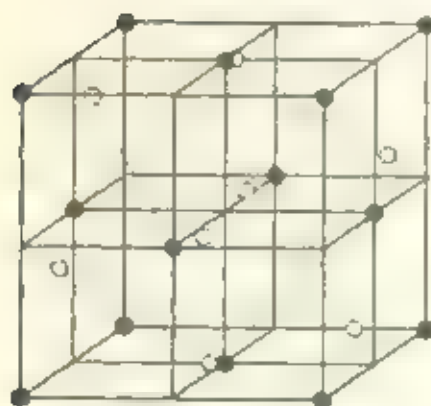
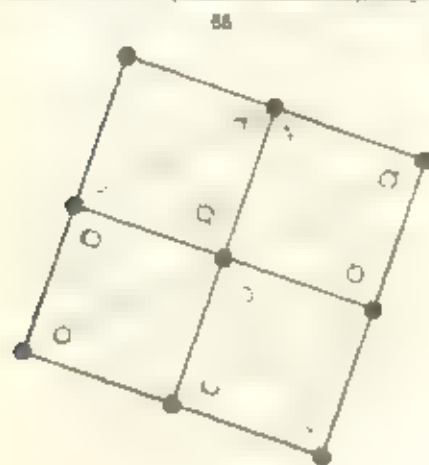
Structure of Graphite parallel to the basal plane



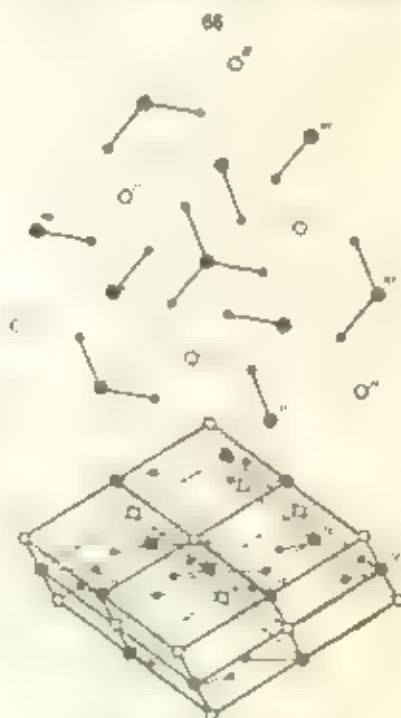
Structure of Fluorite. Ca = ● F = ○

planes that contain the carbon atoms. Passing through the structure parallel to the vertical crystallographic axis, planes containing the calcium atoms alternate with planes containing only the groups of carbon and oxygen. The arrangement of the atoms in the three perpendicular planes of the figure was indicated in Figure 1 and is shown in the following projection.

The above examples illustrate some of the simpler and simpler structures that were studied by X-ray methods. Many other minerals



Structure of Pyrite: Fe = ●, S = ○



Structure of Quartz

○ = Oxygen; ● = Silicon; * = Oxygen

have been examined; some of them, as in the case of various silicates, of considerable complexity. It is impracticable to adequately treat such cases here, and the interested student must be referred to the original papers. The subject is more fully developed in the following books:

- W. H. Bragg and W. L. Bragg: *X-ray and Crystal Structure*, 1924.
 W. H. Bragg: *Introduction to the Crystallography*, 1925.
 G. L. Clarke: *Applied Crystallography*, 1925.
 R. W. G. Wyckoff: *The Structure of Crystals*, 1931.

GENERAL MATHEMATICAL RELATIONS OF CRYSTALS

39. Axial Ratio, Axial Plane.—The crystallographic axes have been defined (Art. 23) as certain lines, the position of which is usually determined by the symmetry of the crystal and which are used in the description of the faces of crystals, and in the determination of their position and angular intersection. With these objects in view certain lengths of these axes are assumed as units to which the occurring faces are referred.

The axes are, in general, lettered a, b, c , to correspond to the scheme in Fig. 67. If two of the axes are equal, they are designated a, a, c , if the three are equal, a, a, a . In one system, the hexagonal, there are four axes, lettered a, a, a, c .

Further, in the systems other than the isometric, one of the horizontal axes is taken as the unit by which the other axes are referred, hence the angular \angle the axes express strictly the *axial ratio*. Thus for sulphur (orthorhombic, see Fig. 67), the axial ratio is

$$a : b : c = 0.8131 : 1 : 1.9084.$$

For rutile (tetragonal) it is

$$a : c = 1 : 0.64415, \text{ or simply, } c = 0.64415.$$

The plane of any two of the axes is called an *axial plane*, and the space included by the three axial planes is an *axial angle*, the total space about the center of the crystal divided by the three axes into eight parts. In the hexagonal system, however, where there are three horizontal axes, the space about the center is divided into twelve parts or *sectors*.

40. Parameters, Indices, Symbol.—*Parameters.* The parameters of a plane consist of a series of numbers which express the relative intercepts of that plane upon the crystallographic axes. They are given in terms of the established unit lengths of these axes. For example, in Fig. 68 let the lines OX, OY, OZ be taken as the directions of the crystallographic axes, and let OA, OB, OC represent their unit lengths, designated always in the same order by the letters a, b, c . Then the intercepts for the plane (1) HKL are OH, OK, OL , for the plane (2) AMN they are OA, ON, OM . But in terms of the unit lengths of the axes these give the following parameters,

$$(1) \quad \frac{1}{a} : \frac{1}{b} : \frac{1}{c}$$

and

$$(2) \quad 1a : \frac{1}{b} : 2c.$$

It is to be noted that since the two planes HKL and AMN are parallel to each other and hence crystallographically the same, these two sets of parameters are considered to be identical. Obviously each of them may be changed into the other by multiplying or dividing by 4.

Indices and Symbol.—Simplified and abbreviated expressions which have been derived from the parameters of a crystal form are commonly used to give its relations to the crystallographic axes. These are known as indices.



A number of different methods of deriving indices have been devised and several are in use at present. The so-called Miller indices are most widely employed, and will be exclusively used in this work.* Below, a description of the other important systems of indices is given together with the necessary directions for transforming one type into another.

The Miller indices may be derived from the parameters of any form by taking their reciprocals and clearing of fractions if necessary. For instance take the two sets of parameters as given above:

$$(1) \frac{1}{a} : \frac{1}{b} : \frac{1}{c}, \text{ and } (2) \frac{1}{a} : \frac{1}{b} : \frac{1}{c}.$$

By inversion of these expressions we obtain

$$(1) 4a : 3b : 2c, \text{ and } (2) 1a : \frac{1}{3}b : \frac{1}{2}c.$$

In the case of (2) it is necessary to clear of fractions, giving

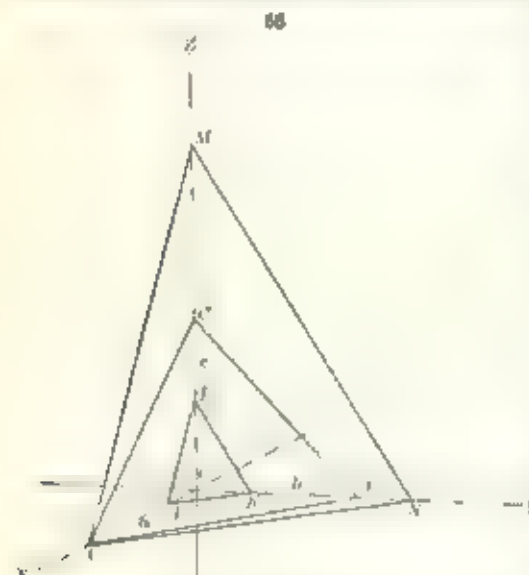
$$(2) 4a : 3b : 2c.$$

The indices of this form then are $4a : 3b : 2c$. The letters indicating the different axes are commonly dropped and the

indices in this case would be written simply as 432 the intercepts on the different axes being indicated by the order in which the numbers are given.

A general expression frequently used for the indices of a form belonging to any crystal system which has three crystallographic axes is hkl . In the hexagonal system which has four axes this becomes $hkil$. If the parameters of a form be written so that they are fractions with the numerators always unity then the denominators will become the same as the corresponding indices. The general expression in this case would therefore be, parameters =

$$\frac{1}{h} \frac{1}{k} \frac{1}{l}$$



form is the indices of the face of that form which has the simplest relations to the crystallographic axes. The symbol is commonly used to designate the whole form.

Various examples are given below illustrating the relations between parameters and indices.

* In the hexagonal system the four axes are those adopted by Bravais after the method of Miller.

Parameters				Muller's Symbol
$\{a, b, c\}$	$= \{a, b, c\}$	$=$	221	
$\{a, b, c\}$	$= \{a, b, c\}$	$=$	212	
$\{a, b, c\}$	$= \{a, b, c\}$	$=$	201	
$\{a, b, c\}$	$= \{a, b, c\}$	$=$	210	
$\{a, b, c\}$	$= \{a, b, c\}$	$=$	100	

If the axial intercepts are measured in *inches* on the x -axis or to the left on the z -axis, or below on the y -axis, they are called negative and a minus sign is placed over the corresponding number of the intercept, as

Parameters	Indices
α	554
β	201

[illegible]

EXAMPLES OF INTEGERS ACCORDING TO VARIOUS SYSTEMS OF NOTATION

Wavelength		Scattering angle	Scattering angle	Scattering angle
10	10	0/2	1/2	1/2
10	20	21/20	21/20	20
10	30	30/21	1/2	20
10	40	40/21	1/2	20

of the face. If the two numbers added or the equal or subtracted

oriented. The Goldschmidt notation is easily converted into the Miller indices by adding 1 to the two figures next to each of the three numbers, and then taking the reciprocals.

The relations between the Miller and the Miller-Bravais indices for the hexagonal system are given in Art. 173.

41. Law of Rational Indices. The study of crystals has established the general law that the ratios between the intercepts on the axes for the different faces on a crystal can always be expressed by rational numbers. These ratios may be $1/2, 2/3, 1/4, 2/3, 1/5, \infty$, etc., but never $1/\sqrt{2}$, etc. Hence the values of hkl in the Miller symbols must always be either whole numbers or zero.

If the form whose intercepts on the axes a, b, c determine their assumed unit lengths—the unit form as it is called—is well chosen, these numerical values of the indices are in most cases very simple. In the Miller symbols, 0 and the numbers from 1 to 6 are most common.

The above law, which has been established as the result of experience, in fact follows from the consideration of the molecular structure as looked at in an earlier paragraph (Art. 31).

42. Form. A form in crystallography includes all the faces which have a like position relative to the planes, or axes, of symmetry. The full meaning of this will be appreciated after a study of the several systems. It will be seen that in the most general case, that of a form having the symmetrical, whose planes meet the assumed unit axes at unequal lengths, there must be forty-eight like faces in the hexagonal system* (see Fig. 159), twenty-four in the hexagonal (Fig. 244), sixteen in the tetragonal (Fig. 205), eight in the orthorhombic (Fig. 49), four in the monoclinic, and two in the triclinic.

In the first four systems the faces named *void* or *essential* form, and hence the form is called a *closed form*. In the remaining two systems this is not true, and such forms in these and other cases are



Basal Prismatic
(001)



Prism
(10, $\bar{1}0$)

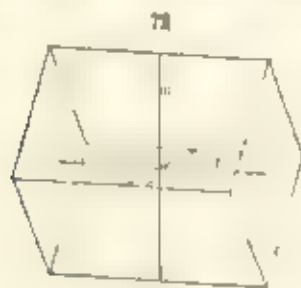
called *open forms*. Fig. 316 shows a crystal bounded by three pairs of unlike faces—each pair is hence an open form. Figs. 70-75 show open forms.

The unit or fundamental form is one where the parameters correspond to the assumed unit lengths of the axes. Fig. 69 shows the unit pyramid of

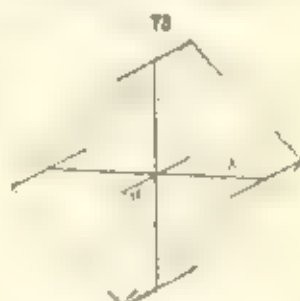
* The normal case is referred to in each case.

sulphur whose symbol is $\{111\}$ it has eight similar faces, the position of which determines the ratio of the axes given in Art. 39.

The forms in the monoclinic system have special names, given later. In the other systems a general name is usually given, but book writers may be briefly mentioned here. A form whose faces are parallel to two of the axes* is called a *prism* (from



Dome
(101), (001)



Prism
(011), (101)

greek *prisma*). It is shown in Fig. 72. One whose faces are parallel to the vertical axis but to both of the horizontal axes is called a *pyramid* (Fig. 73). A form whose faces are parallel to one horizontal axis and to one vertical axis is called a *prism*. If the faces are all the same the form is a *simple prism*. One having a given even number of faces is called a *polyhedron*.

In Fig. 74 $h(010)$ and $k(001)$ are prism and $d(101)$ and $e(021)$ are domes, a and b are pyramids. Figure 75 is a *pyramidal form*. The rule of the face, the number of faces, and the position.

An abbreviation is also given, the symbol of a form is in a box, enclosed in parentheses, as $\{111, 100\}$, or it may be in brackets $[111, 100]$.

43. Zone. A zone includes a series of faces on a crystal whose intersection lines are mutually parallel to each other and to a common line drawn through the center of the crystal called the *zone-axis*. It follows that at edges between the faces that lie in the same zone are mutually parallel to each other and to the zone-axis. Such simple relations of position exist in every case between the faces in a zone, which is expressed by the *zonal equation* (see Art. 60). The faces m, a, b (Fig. 74) are in a zone, also d and e .

If a face of a crystal simultaneously lies in two zones it follows that its symbol is fixed and can be determined from the two zonal equations without the measurement of angles. Further it can be proved that the face corresponding to the intersection of two zones is always a possible crystal face, that is, one having rational values of the indices which define its position.



Chrysoth

* In the tetragonal system the form $\{100\}$ is however called a *prism* and $\{101\}$ a *pyramid*.

In many cases the zonal relation is obvious at sight, but it can always be determined, as shown in Arts. 60, 61 by an easy calculation.

Illustrations will be given after the methods of representing a crystal by the various projections have been explained.

44. Horizontal Projections. — In addition to the usual perspective figures of crystals, projections on the horizontal plane, or more generally the plane normal to the prismatic zone, are very conveniently used. These give a flat map of the crystal as viewed from above, and in the direction of the axis of the prismatic zone. Figs. 30-43 give simple examples. In these the successive faces may be indicated by accents, as in Fig. 74, passing around in the

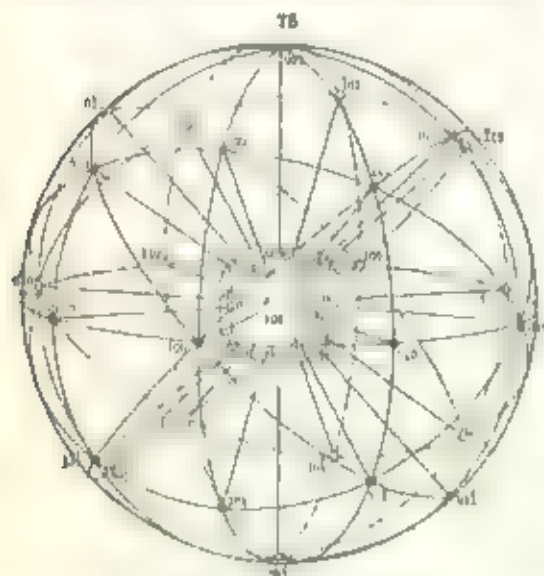
direction of the axes a, b, c , that is, counter-clockwise. On the construction of these projections see Appendix A.

45. Spherical Projection. — The study of actual crystals, particularly regarding the angular and zonal relations of their faces, is much facilitated by the use of various projections. The simplest of these and the one from which the others may be derived is known as the *spherical projection*.

In making a spherical projection of a crystal it is assumed that the crystals lie within a sphere, the center of which coincides with the center of the crystal (i.e. the point of intersection of its crystallographic axes). From this common center normals are drawn to the

successive faces of the crystal and continued until they meet the surface of the sphere. The points at which these normals meet that surface locate the poles of the respective faces and together form the spherical projection of the crystal. The method of formation and the character of the spherical projection are shown in Fig. 75.

It is to be noted that all the poles of faces which lie in the same zone of the crystal, i.e. faces whose intersection lines are mutually parallel fall upon the same great circle on the sphere. This is illustrated in the figure in the case of the zones a, d, a and a, c, d . Conversely, of course, all faces whose poles fall on the same great circle of the sphere, i.e. whose projection must lie in the same zone. A face whose pole falls at the intersection of two or more great circles lies in two or more independent zones, as for instance 011 in Fig. 75. The angular relations between the faces on the crystal are of course preserved in the angles existing between their respective poles in the spherical projection. The angles between the poles, however, are the supplementary angles to

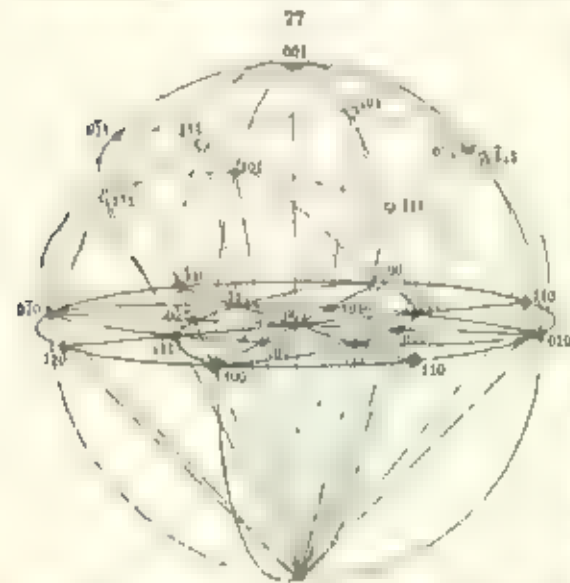


Spherical Projection (after Pentland)

those between the faces on the crystal as shown in Fig. 76. The supplementary angles are those which are commonly measured and recorded when studying a crystal (see Art. 235).

The spherical projection is very useful in getting a mental picture of the relations existing between the various faces and zones upon a crystal but because of its nature does not permit of the close study and accurate measurements one may be made on the other projections described below which are made on plane surfaces.

46. The Stereographic Projection. The stereographic projection may be best considered as derived from the spherical projection in the following manner. The plane of the projection is commonly taken as being at right angles to the sphere. Imaginary lines are drawn from the poles of the spherical projection to the south pole of the sphere, the point in which these lines pierce the plane of the equator become the poles in the stereographic projection. The relation between the two projections is shown in Fig. 77. Fig. 78 shows the same stereographic projection without the effect of measuring of Fig. 77. Commonly only the poles that lie in the northern hemisphere including those on the equator are transferred to the stereographic projection.



Relation between Spherical and Stereographic Projections

(i.e. as arcs of circles having infinite radii). Other great circles on the spherical projection, as already stated will be transferred to the stereographic as circular arcs. Examples of all these are shown in Fig. 78.

When transferring the stereographic projection need to be noted. Its most important character is that all circles or circular arcs on the spherical projection are projected as arcs of true circles on the stereographic projection.* The poles of all crystals that are parallel to the vertical crystallographic axis fall on the equator of the spherical projection and occupy the same positions in the stereographic projection. The pole of a horizontal face will fall at the center of the stereographic projection. All north and south meridians of the spherical projection will appear as straight radial lines in the stereographic projection.

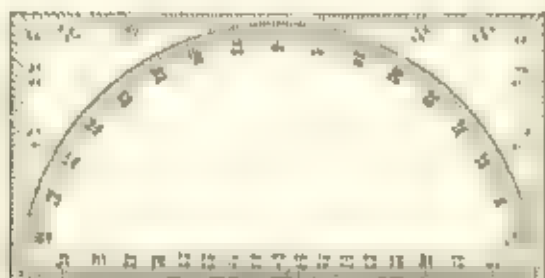
* For proof of this statement see Penfold, Am. Jour. Sci., 11, 10, 601.

20° from N on the sphere is projected to the point a on the stereographic projection, a point 45° from N is projected to b etc. In this way a protractor can be made by means of which angular distances from the center of the stereographic projection can be readily determined. Fig. 80 represents such a protractor which was devised by Penfield.* The mathematical relation between the linear distance from the center of the projection and its angular value is seen by study of Fig. 79. If the radius of the circle of the projection is taken as unity the distance from its center to any terrestrial point is equal to the tangent of one-half of the angle represented. For instance the distance from the center to the point a is equivalent to the tangent of 10° , to point c the tangent of 35° , etc.

Fig. 81 represents a chart used by Penfield for making stereographic projections. The circle has a diameter of 14 cm. and is graduated to degrees. Without its certain scales that are very useful in locating the desired points and great circles. These will be briefly described later.

For detailed descriptions of the principles of the stereographic projection and the mathematics of its use the reader is referred to the various books and articles the titles of which are given below.† It is possible here to give only a brief outline of the more important methods of construction used.

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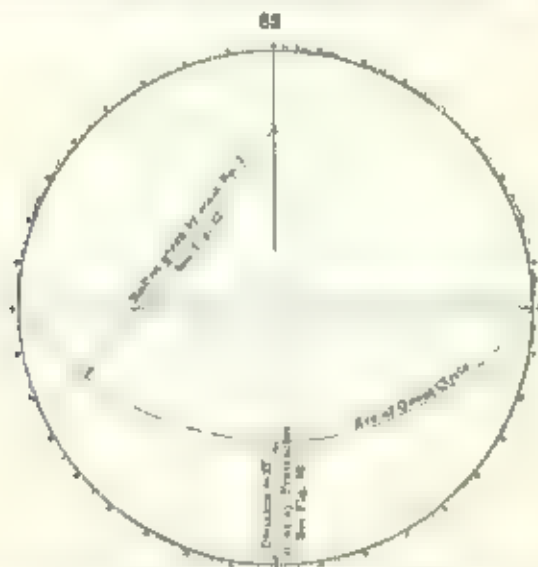
Stereographic Protractor for plotting Stereographic Projections after Penfield, reduced one-half.

(1) To locate the pole of a face lying on a known north and south great circle, its angular distance from the center or a point on the circumference of the projection being given. The stereographic protractor, Fig. 80, or the tangent relation as stated above, gives the proper distance. The points labeled a (geometric center) Fig. 78, may be located in this way.

(2) To locate the projection of the arc of a great circle which is not a north and south meridian or the equator. The projections of three points on the arc must be known. Then since the projection of the circle will be still a circular arc, its position can be determined by the usual geometric construction for a circle with three points on its arc given. If as is commonly the case, the points where the great circle crosses the equator and the angle it makes with the equator are known it is possible to get the radius of the projection directly from scale No. 1 Fig. 81. The location of such a great circle is shown in Fig. 82. The arcs shown in Fig. 78 were also located in this way.

* This protractor and the other instruments and scales used by Penfield can be obtained from the Mineralogical Laboratory of the Sheffield Scientific School of Yale University, New Haven, Connecticut.

(3) To locate the position of the pole of a face lying on a known great circle which is not a north and south meridian. Its angle from a point on the circumference of the projection being known. - The projected arc of a small vertical circle, whose radius is the known angle is drawn about the point on the circumference of the projection and since all points on this arc must have the required angular distance from the given point, the intersection of this circle with the known great circle will give the desired point. The radius of the projected arc of the small vertical circle can be determined by finding the position of three points in the projection which have the required angular distance from the point given on the circumference of the projection and then obtaining the center of the required circle in the usual way. Or by the

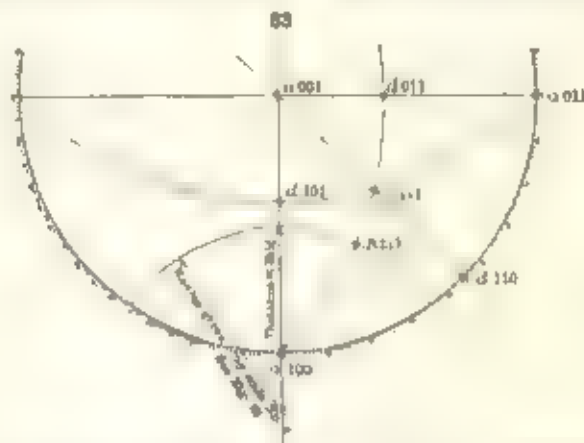


Location of the arc of a great circle in the Stereographic Projection at a given angle above the equator

use of Scale No. 2, Fig. 81, the required radius is obtained directly. It is to be noted that the known point on the circumference of the projection, which is the stereographic center of the small circle is not the actual center of the projected arc. The center will be a point on the circumference of a circle of the radius line that joins the given point with the center of the projection. Therefore, even if the radius of the required arc is taken from Scale No. 2 it will be necessary to extend it at least one point on the required circle in order to find its center. These methods of construction are illustrated in Fig. 83 in which the position is determined of the pole of a triclinic trapezohedron which lies on the great circle passing through the poles of a triclinic octahedron and a triclinic octahedron, and makes a known angle (351°) with it.

(4) To locate the position of the pole of a face given the angles between it and two other faces whose poles are within the stereographic projection. - First inscribe about the poles of the two known points small circles with the proper radii and

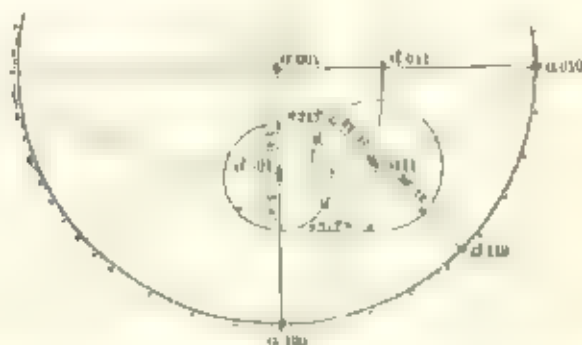
the desired point will be located at their intersection. The two small circles may touch at only a single point or they may intersect at two points. In the latter case both points will meet the required conditions. The positions of the projected small circles are readily found by drawing radii from the



Location of pole of trapezohedron, $a\ 111$, in Stereographic Projection

center of the projection through the two known poles and then laying off on these radii from a center or edge of the known poles with the required angular distances. The center is then found between these two points in each case and a circle drawn through them. The line of this circle will then be everywhere the required number of degrees away from the known pole. The re-

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Location of two poles of hexetahedron, a , in Stereographic Projection

quired points may be found readily by means of the Stereographic Protractor Fig. 80, remembering that the zero point on the protractor must always be at the center of the projection. This construction is illustrated in Fig. 84, in which the points a (geometric hexetahedron), are $22^\circ 12'$ and $19^\circ 5'$ from

the points *b* (isometric octahedron), and *d* (isometric dodecahedron). It is to be noted here also, that while the points *a* and *d* are the stereographic centers of the circles about them, the actual centers are points which are somewhat farther out from the center of the projection.

5) To measure the angle between two given points on the stereographic projection. — If the two points are on the circumference of the projection, draw

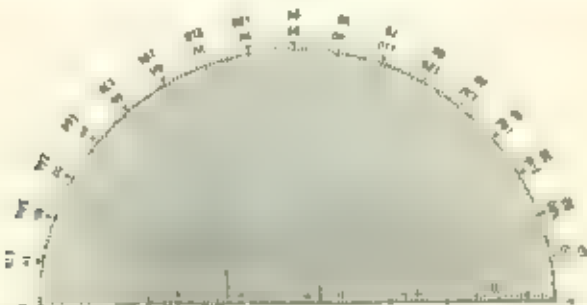
85



Stereographic Protractor giving the great circles of every alternate degree, from 1, fourth etc., to 180. After Pentland, reduced one-half.

angle between them, and read directly from the divisions of the circle. If they lie on the same great circle in the projection, the angle is given by the use of the Stereographic Protractor, Fig. 86. In other cases it is necessary first to find the arc of a great circle upon which the two points lie. This is most easily accomplished by the use of a transparent circular protractor upon which the arcs of great circles are given, Fig. 85. Place this protractor over the projection with its center coinciding with the center of the projection, and

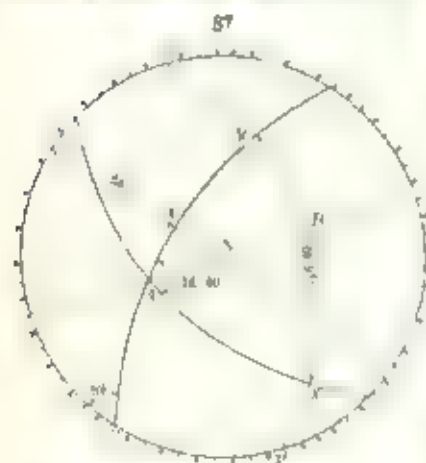
86



Stereographic Protractor giving small circles for every degree measured from a given point on the circumference. After Pentland, reduced one-half.

turn it about until the required great circle is found. Note the points where this circle intersects the circumference of the projection. Then place a second transparent protractor on which small vertical circles are given, Fig. 86, over the projection with its ends on the points of the circumference just determined. Now note the angular distance between the two given points. The whole operation may also be done by use of a third transparent protractor, on which the arcs of both great and small circles are given.

(4) To measure the angle between the arcs of two great circles on the stereographic projection. This is most conveniently accomplished by constructing the arc of a great circle which shall have a 90° radius about the point at which the two arcs in question cross each other and then measuring the angular distance between the two points at which they intersect this great circle. Fig. 87, after Perrier, will serve to thus illustrate the method. First, if it is wished to measure the angle between the divided circle and the arc of the great circle that crosses it at C , it is only necessary to draw a straight line through the center of the projection, N , which shall intersect the divided circle at points 90° distant from C . This line will be the projection of the arc of a great circle about the sphere at 90° distant from C . The angle at C is then determined by measuring with the stereographic protractor the angle between z and p .



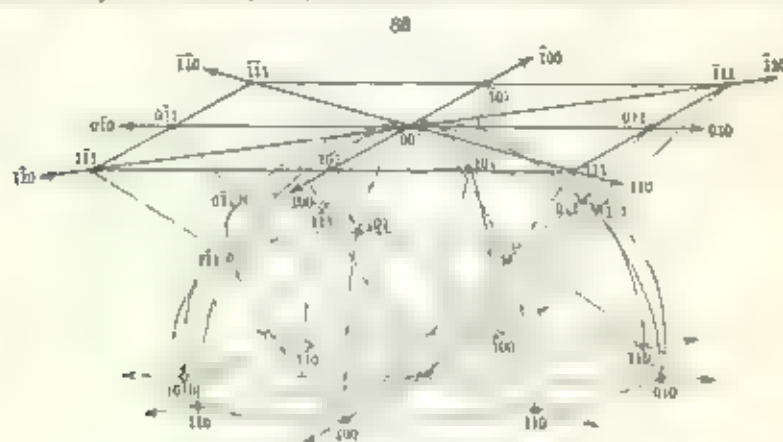
In the case of the angle between two great circles that intersect at some point within the divided circle as at C in Fig. 87, it is necessary to construct the projected arc of the great circle 90° distant from any point. This is done by drawing the radius line through N and C and measuring with the stereographic protractor an angle of 90° from A to the point B . The required arc will pass through this point and the points p and p' which are each 90° away from the points at which the line AC crosses the divided circle. The angle between z and p , measured on this great circle, gives the value of the required angle at A . This is most readily measured by the use of the tracing paper or similar showing small circles, Fig. 86. This is placed across the projection from p to p' and the angle between z and p read directly from it.

Wulff has described a stereographic net, which gives both great and small circles for every two degrees. Over this is placed a sheet of tracing paper upon which the stereographic projection is made. If the paper is fastened at the center of the drawing so as to turn it around, various positions in respect to these stereographic circles below. The various great and small circles needed can be sketched directly upon the tracing. Or the required points can be transferred from the net to a separate drawing by means of three point dividers.

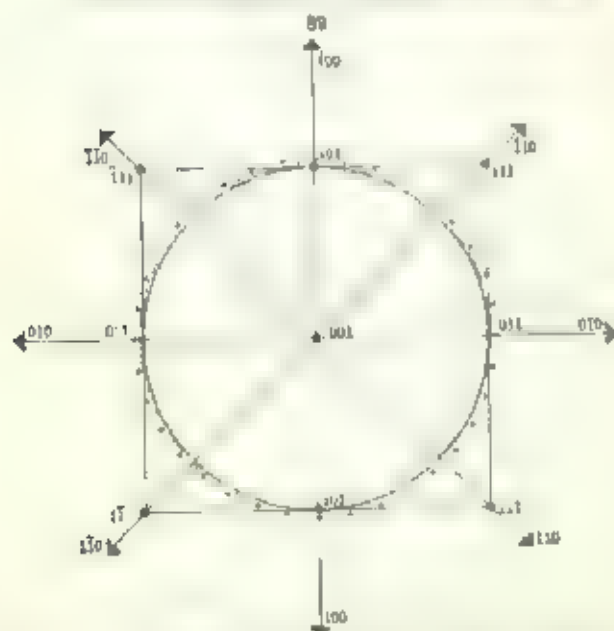
Examples of the use of the stereographic projection will be given later under each crystal system.

47. The Gnomonic Projection. The characters of the gnomonic projection can best be understood by considering it as derived from the spherical projection (see Art. 45). In the case of the gnomonic projection, the plane of the projection is usually taken as the horizontal plane which lies tangent to the north pole of the sphere of the spherical projection. Imaginary lines are then taken from the center of the sphere through the poles of the crystal faces that are on its surface and extended until they reach the plane of the projection. The points in which these lines touch that plane

constitute the gnomonic projection of the forms represented. Fig 88 shows the relations between the spherical and gnomonic projections, using the same isometric crystal forms (cube, octahedron and dodecahedron, as were em-



Relation between Spherical and Gnomonic Projections



Gnomonic Projection of Cube, Octahedron and Dodecahedron

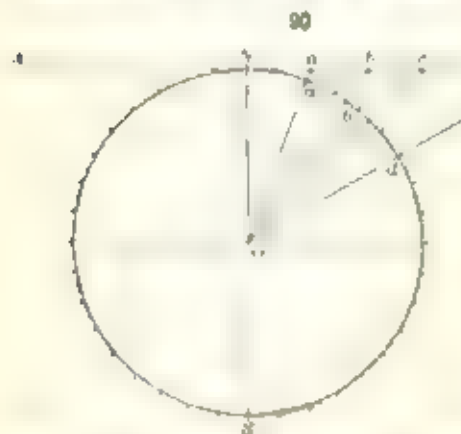
played to illustrate the principles of the Stereographic Projection (Art 46). Fig. 89 shows the gnomonic projection of the same set of forms.

The following features of the gnomonic projection are important. All

great circles on the spherical projection become straight lines when transferred to the gnomonic. The poles of a series of crystal faces which belong to the same zone will therefore on the gnomonic projection lie on a straight line. This primary distinction between the stereographic and gnomonic projections will be readily seen by comparison of Figs 78 and 80. The pole of a horizontal crystal face—like the top face of the cube—will lie at the center of the projection. The poles of vertical crystal faces will lie on the plane of projection only at infinite distances from the center. This is shown by a consideration of Fig. 88. Such faces are habitually indicated on the projection by the use of radial lines or arrows which indicate the directions in which their poles lie. This is illustrated in the case of the vertical cube and corundum faces in Fig. 89. Crystal faces having a steep inclination with

the horizontal plane must frequently be indicated in the same way.

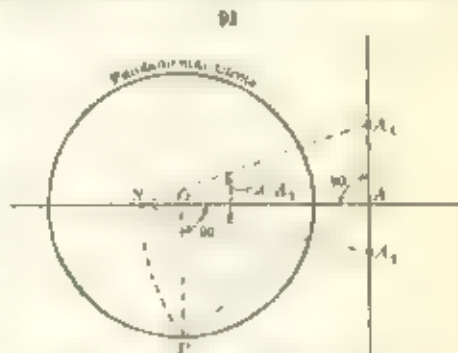
A simple relation exists between the linear distance from the center of the projection to a given point and the angular distance represented. This is shown in Fig. 90 where the circle is assumed to be a vertical cross section of the sphere of the spherical projection and the arc AB represents the trace of the plane of the gnomonic projection.



tion. It is evident from this figure that if the radius of the sphere is taken unity the linear distances OA , OB , etc. are the tangents of the angles 20° , 30° , etc. Consequently in the gnomonic projection the distance from a given pole from the center of the projection, measured in the linear distance OA , Fig. 90, is the same as the tangent of an angle represented by the arc of the stereographic projection that distance is equal to the tangent of one half the angle (see Art. 46). The stereographic scale, used in the stereographic projection, Fig. 80, can therefore be adapted for use in the gnomonic projection by taking the point of reading at twice the desired angle. The simplest method of plotting however is to make a direct use of the tangent relation. The distance OB , Fig. 90, is taken at some convenient length and then by measuring (Fig. 1) a distance by the natural tangent of the angle desired the linear distance of the pole in question from the center of the projection is determined. Frequently the distance OA is taken as unity. In making a gnomonic projection a circle's circumference drawn about the center of the projection, known as the fundamental circle with a radius equal to this chosen distance. Points that have an angular distance of 45° and the center point of the projection will be on the circumference of this circle. Commonly also the gnomonic projection is surrounded by a square border of two parallel lines on which are indicated the directions in which will lie the poles that cannot appear on the projection because of the vertical

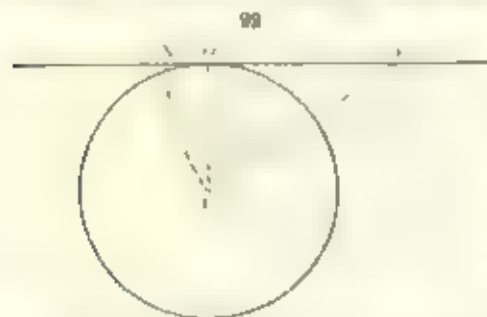
or steeply inclined position of their faces. These characters are shown in Fig. 89.

To measure the angle between two poles on the gnomonic projection — In Fig. 91 let A_1 and A_2 be any two points the angle between which is desired. First draw a straight line through them or, in other words, find the direction of the zonal line upon which they lie. Next erect the line $O-A$ perpendicular to this zonal line and passing through the center O of the projection. On this line establish the point N , the distance $O-A$ being equal to the hypotenuse of the right triangle AOP or the distance $A-P$. The point N is known as the *angle-point* of the zone A_1-A_2 . The angle A_1-N-A_2 is equal to the desired angle between the points A_1 and A_2 . In the case of zonal lines that pass through the center of the projection this angle-point will be on the circumference of the fundamental circle at the terminus of a radius which is at right angles to the zonal line in question. In the case of crystal faces whose poles lie at an infinite distance the center of the projection is itself the angle-point.



Mean tangent of angle between any two poles (A_1-A_2) on the Gnomonic Projection.

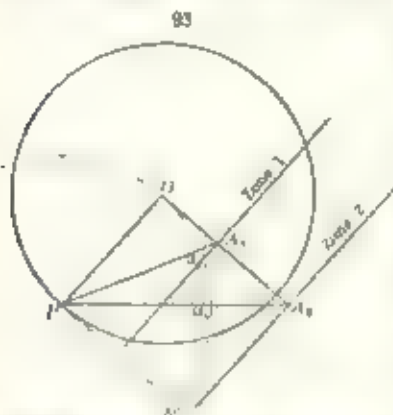
The explanation of the above method may be given as follows. In Fig. 92 let the zone represent a vertical section through the sphere. The spherical section on the line A_1-A_2 is the trace of the plane of the great circle A_1-A_2 . Let the line A_1-A_2 represent the intersection of a zonal plane lying at right angles to the plane of the gnomonic projection and the plane of the sphere. The line A_1-A_2 would therefore be a straight line through point O which would be perpendicular to the plane of the sphere. The angle between any two poles lying on the zone may now be determined. The angle formed by the line drawn from these poles to the point N . If we consider two radial lines $O-A_1$ and $O-A_2$ passing through A_1 and A_2 respectively, the drawing as a whole may be considered as a projection of the plane of the sphere onto the plane of the gnomonic projection. The distance $O-A_1$ is equal to the distance $O-A_2$ and the other to $O-N$. The radius of the fundamental circle is equal to the distance $O-N$.



be determined by drawing lines from N to the two poles and measuring the angle. The point N lies on the line containing the center of the gnomonic projection and the distance $O-N$ is equal to the distance $O-A_1$ and $O-A_2$ of the right triangle $O-A_1-N$ the side of which is equal to $O-N$ and the other to $O-A_1$ or $O-A_2$ the radius of the fundamental circle.

To measure the angle between parallel zonal lines on the gnomonic projection — In Fig. 93 let the two lines Zone 1 and Zone 2 represent two parallel zones. Draw the radial line from the

center of the projection, O at right angles to these zonal lines intersecting them at the points A_1 and A_2 . Make OP at right angles to OA_1A_2 . The angle A_1PA_2 will give the angle between the two zones. The construction will be readily understood if the figure is supposed to be turned on the line OA_1A_2 as on an axis until the point P becomes the center of the spherical projection. The broken arc now represents a vertical cross section of the sphere of the spherical projection and the points a_1 and a_2 the poles where the two zonal lines cross it. The angle at P is obviously the angle between the two zones.



Measurement of the angle between parallel lines on Gnomonic Projection

The gnomonic projection is most commonly used in connection with the measurement of crystal angles by means of the two-circle goniometer. This use will be explained later, see Art. 237. For more detailed descriptions of the principles and uses of the gnomonic projection the reader is referred to the literature listed below.

References on the Stereographic and Gnomonic Projections

In addition to the descriptions of these projections that are given in many general crystallographic texts the following books and papers are of value.

- Barker, T. V. *Gnomonic and Tabular Methods in Crystallography*. 1922.
 Boeck, H. E. *Die Anwendung der stereographischen Projektion in der Kristallographie*. 1. Versuchsgang. 1911. *Die gnomonische Projektion in ihrer Anwendung auf kristallographische Aufgaben*. 1914.
 Evans, J. W. *Gnomonic Projections in two parts*. *Min. Mag.* 14, 149, 1906.
 Gotschmidt, V. *Über Projektion und graphische Kristallzeichnung*. 1887.
 Gosner, B. *Kristalldarstellung aus Kristallzeichnungen*. 1914.
 Hutton, H. *The Gnomonic Net*, *Min. Mag.* 14, 18-20, 1904. *The Construction of Crystallographic Projections*, *Min. Mag.* 14, 99-108, 1906. *Some Applications of the Gnomonic Projection to Crystallography*, *Min. Mag.* 14, 104-115, 1905.
 Hutchinson, A. *Aids to a projector for use in constructing stereographic and gnomonic projections of the sphere*, *Min. Mag.* 13, 94-112, 1908.
 Pausche, Charles. *The Gnomonic Projection*. *Amer. Min.* 5, 67, 1920.
 Penfield, S. I. *The Stereographic Projection and Its Possibilities from a Graphical Standpoint*, *Am. J. Sci.*, 8, 1-24, 115-144, 1901. *On the Solution of Problems in Crystallography by Means of Graphical Methods based upon Spherical or Plane Trigonometry*, *Am. J. Sci.* 14, 249-264, 1902. *On the Drawing of Crystals from Stereographic and Gnomonic Projections*, *Am. J. Sci.*, 31, 396-415, 1910.
 Smith, G. H. H. *On the Advantages of the Gnomonic Projection and its use in the Drawing of Crystals*, *Min. Mag.*, 13, 309-321, 1903.

words a face that truncates the edge between them. Note in Fig. 94 that the indices of c can be obtained by adding the indices of d and f , $101 + 121 = 222$ or 111 ; also by adding the indices of m and k , $(110 + 001) = 111$, etc. All faces to belong to the same zone, *trizonal faces* as they are called, must have their mutual intersections parallel to a given direction, see Art. 43. This direction is known as the axis of the zone. The position of this zonal axis can be expressed by what is known as the zonal symbol. Consider

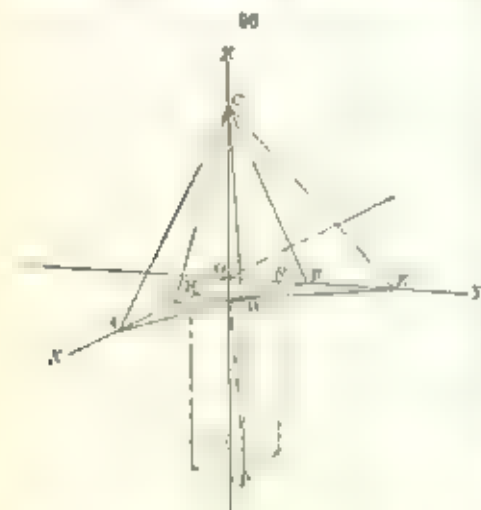


Fig. 94, where are represented two crystal faces AHB' and CDE , intersecting the crystallographic axes X , Y and Z . In the illustration, for simplicity, both faces have been assumed to pass through the point C on the axis Z . This of course, is possible since any crystal plane may be moved parallel to itself without altering its relative intercepts on the crystal axes. These two planes intersect in the line $C-B'$, which then becomes the direction of the zonal axis for the zone in which they lie. Let the line OP which has been drawn parallel to this direction represent that axis. In the parallelogram of which it is a diagonal, the length of the edge OS and its parallel edges have been taken as equal to the distance OC . The point P

$$OM = (kr - lp)a; \quad OR = (lp - hr)b, \quad OS = (hq - kp)c,$$

on the zonal axis and therefore the direction of the axis itself is fixed by the three coordinates OM , OR and OS . By means of the consideration of similar triangles it is possible to prove that the values of these coordinates may be expressed by,

where a , b , c represent the unit lengths of the three crystallographic axes, hkl and $pqrs$ represent the indices of the two faces AHB' and CDE . These expressions are usually simplified by substituting $u = kr - lp$, $v = lp - hr$, $w = hq - kp$, giving $OM = ua$, $OR = vb$ and $OS = wc$. The three figures (pencil) are said to be the symbol of the zone in question. They represent the reciprocal of the values of the three coordinates, or in other words are the indices of a point P on the zonal axis. They may most readily be obtained by a system of cross-multiplication and subtraction according to the following scheme. Write the indices of one face twice in their proper order and lastly under them the corresponding indices of the second face. Cross off the first and last number of each series. Then multiply the figures joined by the cross-arms (see below), and subtract the product of the two joined by light lines from that of those joined by heavy lines, working from left to right. The three numbers obtained will in their order correspond to u , v , and w .

$$\begin{array}{ccccccc}
 A & k & l & k & k & l \\
 | & \diagdown & \diagup & \diagdown & \diagup & \diagdown & | \\
 p & q & r & p & q & r
 \end{array}$$

$$u = kr - lq, \quad v = lp - kr, \quad w = lq - kp.$$

Since the zonal symbol for a given zone may be obtained from the indices of any two faces lying in that zone it follows that the indices of every possible face in that zone must have definite relations to the zonal symbol. For a given face with indices xyz , in a zone having the symbol hkl , the following equations, known as the zonal equations, must hold true:

$$ux + vy + wz = 0.$$

In this way it can be readily shown whether or not a given face can lie in a certain zone.

Further, if hkl be the symbol of one zone and efg that of another intersecting it, then the point of intersection will always be the pole of a possible crystal face. Its indices hkf , must satisfy the equations of both zones and may be obtained by combining them or the same result may be had by taking the symbols of the two zones and subjecting them to the same sort of cross-multiplication by which they were themselves originally derived.

§1. Examples of Zones and Zonal Relations. The following are cases in which the point of intersection of two zones is a crystal face. In face of fig. 65, the faces OK , m (10), a (12), b (01) form a zone, a zone with ab as its pole is obtained, since they are all parallel to the vertex of the crystal, and all faces of a crystal are parallel to the vertex.

Again, the faces a (10), b (01), c (11) form a zone, and being parallel to the horizontal axis, the faces h (10), k (01), l (11) form a zone, since they have c as their pole, for the same reason. We then, already, $h = l$.

The faces h (10), k (01), l (11) are also to a zone, and again $h = l$. The intersections do not depend on a definite between h and l , the one may be h for the other l , or each of these values is true that there is a common ratio of the horizontal components of h to k in the h faces. For the first it may be shown that $h = l$ of the second that is $2h = k$.

A set of coefficients may be assumed at once from the above scheme. For example for the faces a (10) and b (01), the scheme gives

$$\begin{array}{ccccccc}
 1 & 2 & 0 & 1 & 2 & 0 \\
 | & \diagdown & \diagup & | & \diagdown & \diagup & | \\
 1 & 2 & 1 & 1 & 2 & 1
 \end{array}$$

$$u = 2, \quad v = 1, \quad w = 0, \quad \therefore 2h - k = 0, \text{ or } 2h = k.$$

The symbol of a face lying at once in two zones as stated above, must satisfy the zonal equations of both. The value of h may be determined either by combining the equations or by a scheme of cross-multiplication like that given above.

For example, in fig. 66, to suppose the faces h (10), a in the Zone 1, with b (01) and a (11), as in a Zone 2 with p (11) and l (11). These zones give, respectively

$$\begin{array}{ccccccc}
 (1) & 0 & 1 & 0 & 0 & 1 & 0 \\
 | & \diagdown & \diagup & | & \diagdown & \diagup & | \\
 1 & 1 & 1 & 1 & 1 & 1 & 1
 \end{array}$$

$$u = 2, \quad v = 0, \quad w = 1.$$

$$\begin{array}{ccccccc}
 (2) & 1 & 1 & 1 & 1 & 1 & 1 \\
 | & \diagdown & \diagup & | & \diagdown & \diagup & | \\
 0 & 1 & 1 & 0 & 1 & 1 & 1
 \end{array}$$

$$r = 0, \quad s = 1, \quad g = 1.$$

Hence for 1 the zonal equation is $h = 1$, for 2 $k = 1$. By combining these, we obtain $A = 1$, $A = 3$.

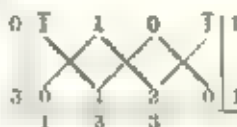
If n is a multiple of the face π is therefore 133.

The same result is given by the zonal equations of $0\bar{1}$, 301 , together after the same method, thus

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Solubur



Hence, again $\pi = 133$.

This result of calculation belongs to all the different systems. In the hexagonal system, however, there are four instead of the three referring to the three principal axes, and the theory is complicated when the zonal relations are applied. See Art. 170.

62. Methods of Calculation.

In general the angles between the poles can be calculated by the methods of spherical trigonometry from the triangles shown in the

spherical projection which for the most part are right angled. Certain fundamental relations connect the axes with the elemental angles of the projection. The most important of these are given under the individual systems. Some general relations only are explained here.

63. Relations between the Indices of a Plane and the Angle made by it with the Axes.

In Fig. 98 at the three lines, X , Y , and Z represent three crystallographic axes making any angles with each other and let a , b , and c represent their unit lengths. Assume any face HKL cutting these axes with the intercepts O H , O K and O L . Let O p P be a normal to the plane HKL intersecting the plane at P and the enveloping surface of the spherical projection at P . The arcs represent bearings of the given form. Since the line O p is normal to the plane HKL the triangles HOp , KOp and LOp are right angles and the following relations hold true

$$\frac{Op}{OH} = \cos HOp, \quad \frac{Op}{OK} = \cos KOp, \quad \frac{Op}{OL} = \cos LOp$$

The angles HOp , KOp and LOp are equal, respectively, to the angles represented in the spherical projection by the arcs PX , PY , and PZ and $OH = \frac{a}{h}$,

$OK = \frac{b}{k}$, $OL = \frac{c}{l}$. By substituting we have,

$$Op = \frac{a}{h} \cos PX = \frac{b}{k} \cos PY = \frac{c}{l} \cos PZ$$

This equation is fundamental, and several of the relations given beyond are deduced from it.

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The most useful application is that when the axial angles are 90° as represented in Fig. 99, then X, Y, Z are the intercepts on OX, OY, OZ respectively. Also if the plane HKL is taken as a face of the unit pyramid, that is, if its intercepts on the axes are taken as the unit lengths

$$OH = a, \quad OK = b, \quad OL = c$$

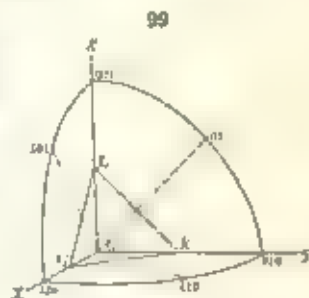
Then the lines HK, HL, KL give also the intercepts. Hence the planes $(100), (010)$ on the three axial planes, and the angles are fixed. A formula for these angles even from Fig. 99 will be obtained from this figure, then, that the following relations hold true

$$\tan (100 \wedge 110) = \frac{a}{b};$$

$$\tan (001 \wedge 101) = \frac{c}{a};$$

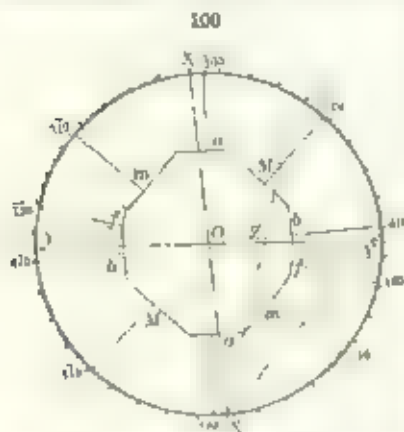
$$\tan (001 \wedge 011) = \frac{c}{b}.$$

These values are often used later.



54. Cotangent and Tangent Relations. In the case of four faces in a zone concerning which we know either the angles between all the faces and the indices of three of them, or the angles between three faces and the indices of two, it is possible by either a simple graphical method of plotting or by extended trigonometry to determine the missing angle or indices.

To illustrate the graphic method first, Fig. 100 represents a cross section perpendicular to the prisms zone of a rhodrite crystal. The traces upon the plane of the drawing of the faces $a(100)$ and $b(010)$ provide the direction of the lines of reference X and Y . It is assumed that the position of the third face $m(110)$ is known and a line drawn parallel to its trace upon the plane of the drawing from the point X will give its relative intercepts upon the two lines of reference. These intercepts do not correspond to the unit lengths of the axes a and b since, rhodrite being triclinic, these axes do not lie in the plane of the drawing but they represent rather the unit lengths of these axes as foreshortened by projection upon that plane. This makes no difference however since it will still be true that the lines lying in the prisms zone of rhodrite must intercept these two lines in distances which will have rational relations to the lengths of the intercepts of $m(110)$. It is now assumed that a fourth face f lies in the zone and its angular position is required. To find the indices of f in the zone is required. From its indices must be ascertained the two lines of reference $X-X'$ and $Y-Y'$ in the ratio of 1 to λ . Let OX equal 1 on $X-X'$ and OZ equal λ on $Y-Y'$. Then a line joining these two points will give the direction of the trace of f upon the plane of the drawing and so determine the angles α will make with the other faces in the zone.



If, on the other hand, the angles between f and the other faces in the zone were known, the position of the trace of f upon the plane of the drawing could be found, and so its relative intercepts (and indices) upon the two axes of reference be determined.



If the method of projection is used, let P , Q , R and S be the poles of four faces in a zone lying in the plane of the drawing, and in an order* that $PQ < PR$ and let the indices of these faces be respectively

$$\begin{array}{cccc} P & Q & R & S \\ hkl & pqr & uvw & xyz \end{array}$$

Then it may be proved that

$$\frac{\cot PQ}{\cot PR} = \frac{\cot PR}{\cot PS} = \frac{PQ}{QR} = \frac{SR}{RS}$$

where

$$\begin{array}{l} \begin{array}{c} 1 \times 1 \\ (PQ) \left(\begin{array}{c} P \\ Q \end{array} \right) \left(\begin{array}{c} h \\ p \end{array} \right) \\ (QR) \left(\begin{array}{c} Q \\ R \end{array} \right) \left(\begin{array}{c} p \\ u \end{array} \right) \end{array} \quad \begin{array}{c} 1 \times 2 \\ \begin{array}{c} P \\ Q \end{array} \left(\begin{array}{c} h \\ p \end{array} \right) \left(\begin{array}{c} u \\ v \end{array} \right) \end{array} \quad \begin{array}{c} 2 \times 2 \\ \begin{array}{c} P \\ Q \end{array} \left(\begin{array}{c} h \\ p \end{array} \right) \left(\begin{array}{c} u \\ v \end{array} \right) \end{array} \quad \begin{array}{c} 3 \times 1 \\ \begin{array}{c} P \\ Q \\ R \end{array} \left(\begin{array}{c} h \\ p \\ u \end{array} \right) \left(\begin{array}{c} v \\ w \end{array} \right) \end{array} \end{array}$$

If one of these fractions reduces to an indeterminate form $\frac{0}{0}$, then one of the angles must be known or deduced.

For example, a crystal may be the monoclinic and rhombohedral systems, and some special cases are referred to among these systems.

The cotangent relation becomes much simplified for a rectangular zone, that is, a zone between a pinacoid and a face lying in a zone at right angles to each other, the angle PR becomes 90° . For example, let hkl and pqr be two faces lying in the zone between $ab(10)$ and $c(01)$ with an angle α and $d = 90^\circ$. Let P_0 and Q_0 represent the angles between the two faces and the pinacoid a . Then the following holds: \cot ,

$$\frac{h}{p} \times \tan P_0 = \frac{k}{q} = \frac{l}{r}$$

or if the faces P and Q lie in zones with the other pinacoids $b(10)$ or $c(01)$, the expression becomes

$$\begin{array}{l} \frac{h}{p} = \frac{k}{q} \times \tan P_0 = \frac{l}{r} \\ \frac{h}{p} = \frac{k}{q} \times \tan Q_0 = \frac{l}{r} \\ \frac{h}{p} = \frac{k}{q} \times \frac{1}{\tan P_0} \\ \frac{h}{p} = \frac{k}{q} \times \frac{1}{\tan Q_0} \end{array}$$

* In the application of this principle, it is essential that the planes should be taken in the proper order, as shown above, to accomplish this it is often necessary to use the indices and corresponding angles not of hkl , but the ones opposite hkl , etc.

If the zone in question lies between two pinacoids which are at right angles to each other so that the indices of the faces P and Q become either $hk0$ and $pq0$, $h0l$ and $p0r$ or $0kl$ and $0qr$, we have

$$\begin{aligned}\frac{\tan (100 \wedge h k 0)}{\tan (100 \wedge p q 0)} &= \frac{h}{p} \cdot \frac{p}{q} ; \\ \frac{\tan (001 \wedge h 0 l)}{\tan (001 \wedge p 0 r)} &= \frac{h}{p} \cdot \frac{r}{l} ; \\ \frac{\tan (010 \wedge 0 k l)}{\tan (010 \wedge 0 q r)} &= \frac{k}{q} \cdot \frac{r}{l} .\end{aligned}$$

These equations are the ones ordinarily employed to determine the symbol of any prismatic zone or dihedron.

The most common and important application of this tangent principle is where the positions of two faces 110, 101, 011 are known, then the relation becomes

$$\begin{aligned}\frac{\tan (110 \wedge h k 0)}{\tan (110 \wedge l 1 0)} &= \frac{k}{l} \quad \text{or} \quad \frac{\tan (010 \wedge h k l)}{\tan (010 \wedge l 1 0)} = \frac{k}{l} \\ \frac{\tan (001 \wedge h 0 l)}{\tan (001 \wedge l 0 k)} &= \frac{h}{k} \quad \text{or} \quad \frac{\tan (001 \wedge h k l)}{\tan (001 \wedge l 1 0)} = \frac{h}{l}\end{aligned}$$

Also,

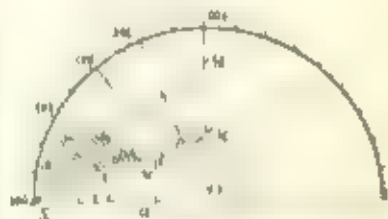
Thus the tangents of angles between the faces 001 and 010, 011 and 001 are respectively $\frac{1}{2}$ and $\frac{1}{2} \sqrt{3}$ and the tangent of the angle between 001 and 011. Again the tangent of the angle $100 \wedge 110$ is twice the tangent of $100 \wedge 110$ (see $\frac{k}{h} = 2$) and one-half the tangent of $010 \wedge 110$.

These relations are shown clearly in Fig. 102 which represents a cross section of a crystal resulting from the intersection of a zone between σ 100 and 001. It is assumed that the angles between the faces σ , α , β , γ and δ have been measured and the positions of their poles determined and plotted on the log σ . The broken lines drawn from a point X on the arc representing σ represent the great circles of the traces of these faces upon the plane of the σ -axis. If the face σ possesses α be the angle σ and 101 it will intersect the σ -axis at a distance proportional to the unit length, namely at X on 101. The other faces α , β , γ and δ are seen to intersect the σ -axis at Y and Z the distance XY being three times the distance YZ or $1/104$. But the distance XY or YZ is the face σ of 101 are proportional to the sines of the angles between their poles and that of 101 as shown below:

$$\begin{aligned}\frac{\tan (54^\circ 10')}{\tan (34^\circ 51')} &= \frac{16142}{4050} = 4 \\ \frac{\tan (21^\circ 54')}{\tan (10^\circ 41')} &= \frac{4028}{1007} = 4\end{aligned}$$

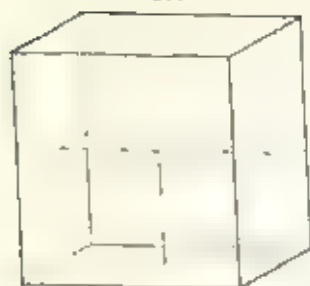
102

$\frac{1}{2}$



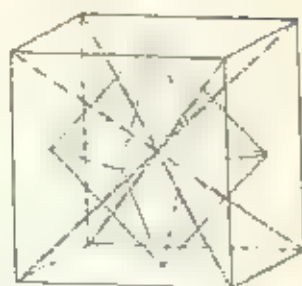
Note. For a simple demonstration of the so-called law of Miller, see Costro, Min. Mag. 17, 324, 1916.

104



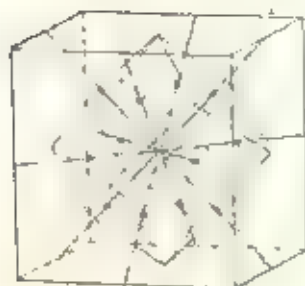
Axes of Tetragonal Symmetry
(Cubic Axes)

105



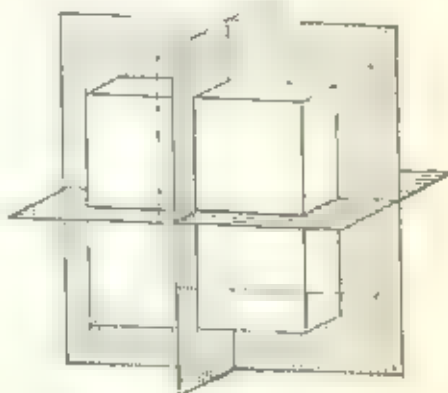
Axes of Trigonal Symmetry
(Octahedral Axes)

106



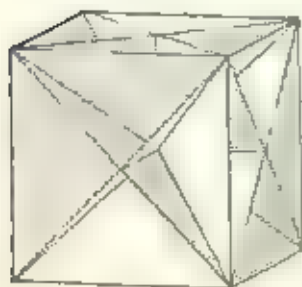
Axes of Binary Symmetry
(Dodecahedral Axes)

107



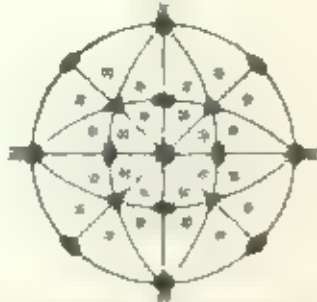
Principal Symmetry Planes

108



Diagonal Symmetry Planes

109



Symmetry of Normal Class,
isometric system

angles made by the cubic axes. These are perpendicular to the faces of the dodecahedron and are known as the dodecahedral axes. These symmetry axes are shown in the Figs. 104-106.

Planes of Symmetry.—There are three principal planes of symmetry which are at right angles to each other and whose intersections fix the position of the crystallographic axes, Fig. 107. In addition there are six diagonal planes of symmetry which bisect the angles between the principal planes, Fig. 108.

The accompanying stereographic projection (Fig. 109), constructed in accordance with the principles explained in Art. 49, shows the distribution of the faces of the general form, hkl hexoctahedron, and hence represents clearly the symmetry of the class. Compare also the projections given later.

57. Forms.—The various possible forms belonging to this class, and possessing the symmetry defined, may be grouped under seven types of solids. These are enumerated in the following table, commencing with the simplest.

	Indices
1. Cube	(100)
2. Octahedron	(111)
3. Dodecahedron	(110)
4. Tetrahedron	hkl as, (310) , (210) , (320) , etc.
5. Trisoctahedron	hkl as, (331) , (221) , (332) , etc.
6. Trapezohedron	hkl as, (411) , (211) , (322) , etc.
7. Hexoctahedron	hkl as, (421) , (321) , etc.

Attention is called to the letters informally used in this work and in Dana's System of Mineralogy, 1892, to designate certain of the isometric forms.* They are

Cube	a
Octahedron	o
Dodecahedron	d
Tetrahedron	$r = 310, f = 210, g = 320, h = 410$
Trisoctahedron	$p = 221, q = 331, r = 332, s = 441$
Trapezohedron	$m = 411, n = 211, p = 322$
Hexoctahedron	$u = 421, v = 321$

58. Cube.—The *cube*, whose general symbol is (100) , is shown in Fig. 110. It is bounded by six similar faces, each parallel to two of the axes. Each face is a square, and the interfacial angles are all 90° . The faces of the cube are parallel to the principal or axial planes of symmetry.

59. Octahedron. The *octahedron*, shown in Fig. 111, has the general symbol (111) . It is bounded by eight similar faces, each meeting the three axes at equal distances. Each face is an equilateral triangle with plane angles of 60° . The normal interfacial angle $(111) \wedge (111)$ is $70^\circ 31' 44''$.

60. Dodecahedron.—The *rhombic dodecahedron*† shown in Fig. 112, has the general symbol (110) . It is bounded by twelve faces, each of which meets two of the axes at equal distances and is parallel to the third axis.

* The usage followed here, as also in the other system, is in most cases that of Miller (1869).

† The dodecahedron of the crystallographer is this form with rhombic shaped faces, sometimes also called *rhombicuboctahedron*. It is not to be confused with a dodecahedron composed of twelve equilateral faces, a form which is regular as well as dodecahedral in the most appropriate sense. In crystallography this solid is distinguished though the *truncated octahedron* approximately. See Art. 72.

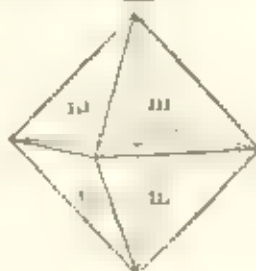
Each face is a rhomb with plane angles of $70\frac{1}{2}^\circ$ and $109\frac{1}{2}^\circ$. The normal interfacial angle is 60° . The faces of the tetrahedron are parallel to the six primary, or diagonal, planes of symmetry.

110



Cube

111



Octahedron

112



Dodecahedron

It will be remembered that, while the forms described are designated respectively by the symbols 100, 111 and 112, each face on any one of the forms has its own indices. Thus for the cube the six faces have the indices

$$100, 010, 001, 100, 010, 001$$

For the octahedron the indices of the eight faces are

$$\begin{array}{cccc} \text{Above} & 111 & \bar{1}\bar{1}1 & 11\bar{1} & \bar{1}\bar{1}\bar{1} \\ \text{Below} & \bar{1}\bar{1}\bar{1} & 111 & \bar{1}\bar{1}1 & 11\bar{1} \end{array}$$

For the dodecahedron the indices of the twelve faces are

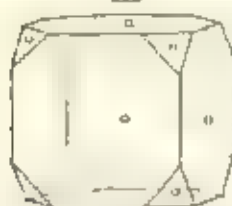
$$\begin{array}{cccc} 110, & \bar{1}\bar{1}0, & 1\bar{1}\bar{1}, & 1\bar{1}0, \\ 011, & \bar{0}\bar{1}\bar{1}, & 10\bar{1}, & 10\bar{1}, \\ 01\bar{1}, & 0\bar{1}1, & 0\bar{1}\bar{1}, & 01\bar{1} \end{array}$$

These should be carefully studied with reference to the figures and to models, and also to the projections, Figs. 113, 114. The student should become thoroughly familiar with these three sets of indices and the relations to the axes which they express, so that he can give at once the indices of any face required.

61. Combinations of the Cube, Octahedron, and Dodecahedron.

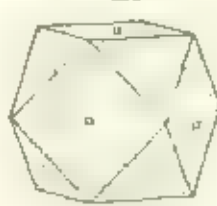
Figs. 113, 114 represent combinations of the cube and octahedron, Figs.

113



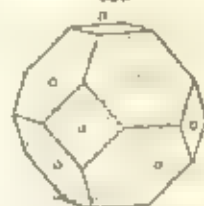
Cube and Octahedron

114



Cube and Octahedron

115



Octahedron and Cube

116, 119 of the cube and dodecahedron, Figs. 117, 118 of the octahedron and dodecahedron, finally Figs. 120, 121 show combinations of the three forms. The predominant form, as in the cube in Fig. 113, the octahedron in Fig. 115, etc. is usually said to be modified by the faces of the other forms. In Fig. 114 the cube and octahedron are sometimes said to be "in equilibrium."

since the faces of the octahedron meet at the middle points of the edges of the cube.

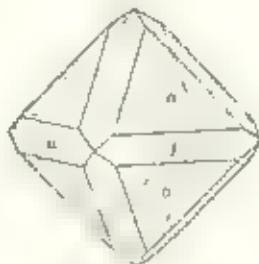
It should be carefully noticed further, that the octahedral faces replace the solid angles of the cube, as regular triangles equally inclined to the adja-

116



Dodecahedron and Cube

117

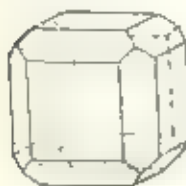
Octahedron and
Dodecahedron

118

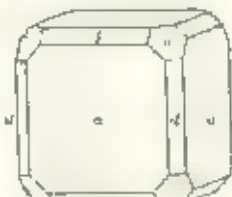
Dodecahedron and
Octahedron

cent cube faces, as shown in Fig. 113. Again, the square cube faces replace the six solid angles of the octahedron, being equally inclined to the adjacent octahedral faces (Fig. 115). The faces of the dodecahedron *truncate** the twelve similar edges of the cube, as shown in Fig. 119. They also truncate the twelve edges of the octahedron (Fig. 117). Further, in Fig. 116 the cubic

119

Cube and Dodeca-
hedron

120

Cube, Octahedron and
Dodecahedron

121

Octahedron, Cube and
Dodecahedron

faces replace the six tetrahedral solid angles of the dodecahedron, while the octahedral faces replace its eight tetrahedral solid angles (Fig. 118).

The normal interfacial angles for adjacent faces are as follows:

Cube on octahedron, $ao, 100 \wedge 111 = 54^\circ 43' 8''$.

Cube on dodecahedron, $ad, 100 \wedge 110 = 45^\circ 0' 0''$.

Octahedron on dodecahedron, $ea, 111 \wedge 110 = 35^\circ 15' 52''$.

62. As explained in Art. 18 actual crystals always deviate more or less widely from the ideal model; consequently, the faces are not always of like faces. Such crystals, therefore, do not satisfy the geometrical condition of right symmetry relative to the three principal and the six auxiliary planes, as required in § 7. But they are conform to the condition of crystallographic symmetry, requiring like angles position for similar faces. Again, it will be noted that in a model is contained many of the faces do not actually meet

* The words *truncate* *truncate* are used only when the modifying face makes equal angles with the adjacent similar faces.

The faces of the tetrahedron hovel* the twelve similar edges of the cube, as in Fig. 125, they replace the solid angles of the octahedron by four faces inclined on the edges (Fig. 125, $f = 310$), and also the tetrahedral solid angles of the dodecahedron by four faces inclined on the faces (Fig. 127, $h = 410$).

54. Trioctahedron. The *trioctahedron* (*triksoctahedron*, Fig. 128) is bounded by twenty-four similar faces, each of these is an isosceles triangle, and three together occupy the position of an octahedral face, whence the common name. Further to distinguish it from the (trapezoidal or tetragonal) *trapezohedron* it is sometimes called the *trigonal trioctahedron*. There are two kinds of edges, lettered *A* and *B* in Fig. 128, and the interfacial angle corresponding to either is sufficient for the determination of the special symbol.

The general symbol is *hhd*, common forms are (221), 311, etc. Each face of the trioctahedron meets two of the axes at a distance less than unity



Trioctahedron



Cube and Trioctahedron



Octahedron and Trapezohedron

and the third at the unit length, or which is an identical expression if *h* is less than unity of the axes at the unit length and the third is a distance greater than unity. The indices corresponding to each face should be read by *h*, *a*, *d*. The normal interfacial angles for some of the more common forms are given on a later page.

55. Trapezohedron. The *trapezohedron* (*trapezohedron*, Figs. 131, 132) is bounded by twenty-four similar faces, each of which is a quadrilateral or trapezoid. It also bears a resemblance to certain trapezoids in the octahedron, whence the name, sometimes applied to *tetragonal trapezohedron*. There are two kinds of edges, lettered *B* and *C* in Fig. 131. The general symbol is *hkl*, common forms are 311, 211, 322, etc. Of the faces, each cuts an axis at a distance less than unity, and the other two at the unit length, or (again) an identical expression, one of them intersects an axis at the unit length and the other two at equal distances greater than unity. The indices

* The word *hovel* is good when $h = 1$. The faces replace the edges of a form, and hence are *hovel* in the place of the edges of a form, $h = 1$, $h = 1$, $h = 1$.

* The word *hovel* is good when $h = 1$. The faces replace the edges of a form, and hence are *hovel* in the place of the edges of a form, $h = 1$, $h = 1$, $h = 1$.

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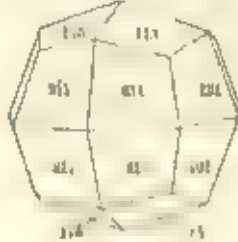
belonging to each face should be carefully noted. The normal interfacial angles for some of the common forms are given on a later page.

98. The combinations of these forms with the cube, octahedron, etc., should be carefully studied. It will be seen, Fig. 129, that the faces of the trisoctahedron repeat the solid angles of the cube as three faces equally

131

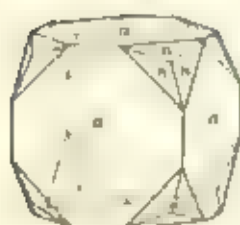


132



Trapezohedron

133

Anatase, Octahedron
and Trapezohedron

134

Analcite, Trisoctahedron
and Octahedron

135

Garnet, Trapezohedron
and Dodecahedron

136

Garnet, Dodecahedron
and Trapezohedron

137

Spinel, Trisoctahedron
and Trapezohedron

138

Magnetite, Dodecahedron
and Trapezohedron

inclined on the edges; this is a combination which has not been observed on crystals. The faces of the trapezohedron appear as three equia. triangles equally inclined to the cubic faces, Fig. 135.

Again, the faces of the trisoctahedron bisect the edges of the octahedron, Fig. 136, while those of the trapezohedron are triangles inclined to the faces at the extremities of the cubic axes, Fig. 137, $m:3:1$. Still again, the faces

of the trapezohedron $m(211)$ truncates the edges of the dodecahedron (110) , as shown in Fig. 136, this can be proved to follow at once from the zonal relations (Arts 50, 61), of also Figs 143, 144. The position of the faces of the form $m(211)$, in combination with a , is shown in Fig. 137, with d in Fig. 138.

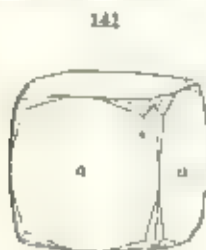
It should be noted that the trapezohedron $m(211)$ is a common form both alone and in combination, $m(341)$ is common in combination. The trisoctahedron alone is rarely met with though in combination. Fig. 139, it is not uncommon.

67. Hexoctahedron. The *hexoctahedron hexakis-tetrahedron*, Figs 139, 140, is the 48th form in this system. It is characterised by forty-eight similar faces, each of which is a scalene triangle, and each intersects the three axes



at unequal distances. The general symbol is hkl , where a forms are $a(321)$, shown in Fig. 139, and $b(421)$ in Fig. 140. The faces on the vertical faces, as shown in Fig. 139, to more fully illustrate proper use, Figs 143, 144, should be carefully studied.

The hexoctahedron has three kinds of edges, a , b , c , a longer, b half, shorter in Fig. 140, the angles of two of these edges are related to



Fluorite. Cube and hexoctahedron.



Garnet. Dodecahedron and hexoctahedron.

for the symbol unless the angle relation can be made use of. In Fig. 142 the faces of the hexoctahedron level the dodecahedron edges, and hence for this form $b = k + 1$. The form a has the special symbol (321) . The hexoctahedron alone is a very rare form, but it is not in combination with the cube (Fig. 135), fluorite, as six small faces occupying each solid angle. Fig. 141 is common with garnet.

68. **Pseudo-symmetry in the Isometric System.**—Isometric forms, by development at the direction of one of the three axes, simulate tetragonal forms. More common, and of greater interest, are forms simulating those of rhombohedral symmetry by extension, or by flattening, in the direction of one of the three axes. Both these cases are illustrated later. Conversely certain rhombohedral forms resemble at some critical distance angles

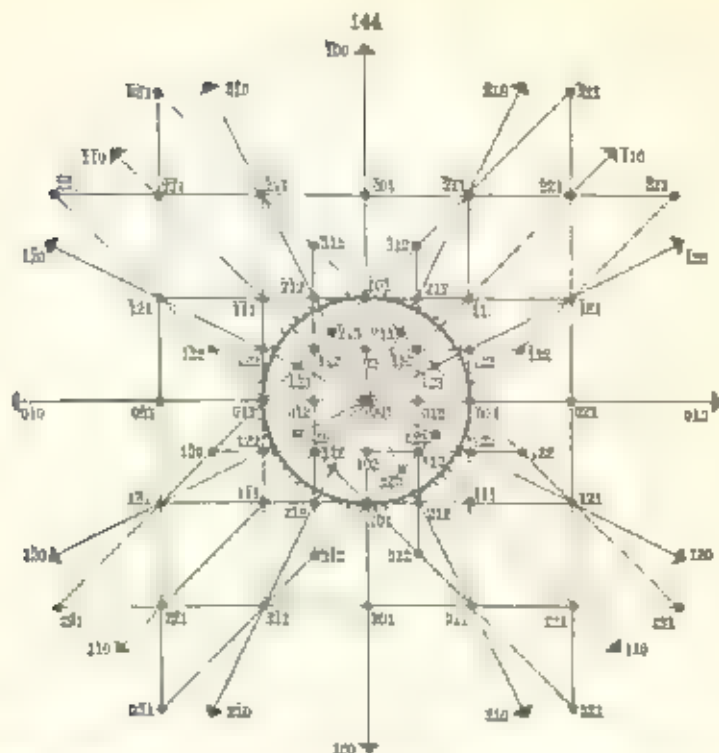
69. **Stereographic and Gnomonic Projections.** The stereographic projection, fig. 142, and gnomonic projection, fig. 144, show the positions



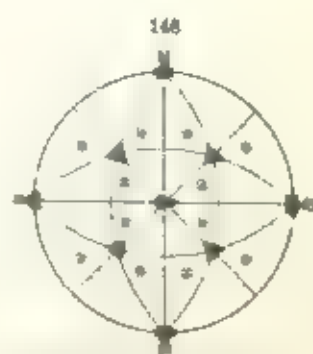
Fig. 142. Stereographic projection of isometric forms. The 100, 110, 111, 112, 113, 114, 115, 116, 117, 118, 119, 120, 121, 122, 123, 124, 125, 126, 127, 128, 129, 130, 131, 132, 133, 134, 135, 136, 137, 138, 139, 140, 141, 142, 143, 144, 145, 146, 147, 148, 149, 150, 151, 152, 153, 154, 155, 156, 157, 158, 159, 160, 161, 162, 163, 164, 165, 166, 167, 168, 169, 170, 171, 172, 173, 174, 175, 176, 177, 178, 179, 180, 181, 182, 183, 184, 185, 186, 187, 188, 189, 190, 191, 192, 193, 194, 195, 196, 197, 198, 199, 200.

of the poles of the forms in the isometric system. The 100, 110, 111, and 112 forms are also the vertices of the 240° tetrahedron. The 111, 112, 113, 114, 115, 116, 117, 118, 119, 120, 121, 122, 123, 124, 125, 126, 127, 128, 129, 130, 131, 132, 133, 134, 135, 136, 137, 138, 139, 140, 141, 142, 143, 144, 145, 146, 147, 148, 149, 150, 151, 152, 153, 154, 155, 156, 157, 158, 159, 160, 161, 162, 163, 164, 165, 166, 167, 168, 169, 170, 171, 172, 173, 174, 175, 176, 177, 178, 179, 180, 181, 182, 183, 184, 185, 186, 187, 188, 189, 190, 191, 192, 193, 194, 195, 196, 197, 198, 199, 200.

The 100, 110, 111, 112, 113, 114, 115, 116, 117, 118, 119, 120, 121, 122, 123, 124, 125, 126, 127, 128, 129, 130, 131, 132, 133, 134, 135, 136, 137, 138, 139, 140, 141, 142, 143, 144, 145, 146, 147, 148, 149, 150, 151, 152, 153, 154, 155, 156, 157, 158, 159, 160, 161, 162, 163, 164, 165, 166, 167, 168, 169, 170, 171, 172, 173, 174, 175, 176, 177, 178, 179, 180, 181, 182, 183, 184, 185, 186, 187, 188, 189, 190, 191, 192, 193, 194, 195, 196, 197, 198, 199, 200.



Gnomonic Projection of Isometric Forms. Circle 100, Octahedron 11, Dodecahedron 110, Tetrahedron 111, Hexoctahedron 112, Tricuboctahedron 113, Truncated Octahedron 114, Truncated Dodecahedron 115, Truncated Icosahedron 116, Truncated Dodecahedron 117, Truncated Octahedron 118, Truncated Dodecahedron 119, Truncated Octahedron 120, Truncated Dodecahedron 121, Truncated Octahedron 122, Truncated Dodecahedron 123, Truncated Octahedron 124, Truncated Dodecahedron 125, Truncated Octahedron 126, Truncated Dodecahedron 127, Truncated Octahedron 128, Truncated Dodecahedron 129, Truncated Octahedron 130, Truncated Dodecahedron 131, Truncated Octahedron 132, Truncated Dodecahedron 133, Truncated Octahedron 134, Truncated Dodecahedron 135, Truncated Octahedron 136, Truncated Dodecahedron 137, Truncated Octahedron 138, Truncated Dodecahedron 139, Truncated Octahedron 140, Truncated Dodecahedron 141, Truncated Octahedron 142, Truncated Dodecahedron 143, Truncated Octahedron 144, Truncated Dodecahedron 145, Truncated Octahedron 146, Truncated Dodecahedron 147, Truncated Octahedron 148, Truncated Dodecahedron 149, Truncated Octahedron 150, Truncated Dodecahedron 151, Truncated Octahedron 152, Truncated Dodecahedron 153, Truncated Octahedron 154, Truncated Dodecahedron 155, Truncated Octahedron 156, Truncated Dodecahedron 157, Truncated Octahedron 158, Truncated Dodecahedron 159, Truncated Octahedron 160, Truncated Dodecahedron 161, Truncated Octahedron 162, Truncated Dodecahedron 163, Truncated Octahedron 164, Truncated Dodecahedron 165, Truncated Octahedron 166, Truncated Dodecahedron 167, Truncated Octahedron 168, Truncated Dodecahedron 169, Truncated Octahedron 170, Truncated Dodecahedron 171, Truncated Octahedron 172, Truncated Dodecahedron 173, Truncated Octahedron 174, Truncated Dodecahedron 175, Truncated Octahedron 176, Truncated Dodecahedron 177, Truncated Octahedron 178, Truncated Dodecahedron 179, Truncated Octahedron 180, Truncated Dodecahedron 181, Truncated Octahedron 182, Truncated Dodecahedron 183, Truncated Octahedron 184, Truncated Dodecahedron 185, Truncated Octahedron 186, Truncated Dodecahedron 187, Truncated Octahedron 188, Truncated Dodecahedron 189, Truncated Octahedron 190, Truncated Dodecahedron 191, Truncated Octahedron 192, Truncated Dodecahedron 193, Truncated Octahedron 194, Truncated Dodecahedron 195, Truncated Octahedron 196, Truncated Dodecahedron 197, Truncated Octahedron 198, Truncated Dodecahedron 199, Truncated Octahedron 200.



Symmetry of Pyramidal class

010, 010, 101, 010. Note further that the faces of a given form are symmetrical & distributed about a cubic face, so 001, a dodecahedral face, is 01, an octahedral face, as 111.

Note further the symbols that belong to the individual faces of each form, comparing the projections with the figures which precede.

Finally, note the *zone* lines of *poles*: for example, the zone between two cubic faces including a dodecahedral face and the faces of an *opposite* tetrahedron. Again, the faces from a cubic face as 100, the right an octahedral face, as 11, to a dodecahedral face, as 011, passing through the tetrahedron as 011, 211, 312, etc.; the dodecahedron as 201, 121, 132, etc. Also the zone from one dodecahedral face, as 110, to another as 011, passing through 121, 211, 312, etc. At the same time compare these zones with the same zones shown on the figures already described. A study of the relations indicated in Fig. 145 will be most useful. From it is seen that any crystal face falling in the zone between the cube and octahedron must belong to a tetrahedron; any face falling in the zone between the cube and dodecahedron must belong to a hexahedron; any face falling in the zone between the octahedron and dodecahedron must belong to a trisoctahedron; further, any face falling outside these three zones must belong to a hexoctahedron.

70. Angles of Common Isometric Forms.*

TETRAHEDRONS.

Cf. Fig. 122.	Edge A 210, A 201, etc.	Edge C 210, A 120, etc.	Angle on a 100.	Angle on a 111.
410	16° 45'	61° 55'	14° 24'	47° 44'
310	23° 50'	53° 14'	15° 36'	43° 54'
520	30° 37'	46° 53'	21° 48'	31° 22'
210	36° 52'	36° 52'	26° 34'	29° 14'
530	42° 40'	28° 4'	30° 57'	27° 37'
320	46° 11'	22° 37'	33° 41'	26° 48'
430	50° 12'	16° 15'	36° 52'	24° 4'
540	52° 25'	12° 40'	38° 39'	23° 45'

TRISOCTAHEDRONS.

Cf. Fig. 124.	Edge A 221, A 212, etc.	Edge B 221, A 211, etc.	Angle on a 100.	Angle on a 111.
432	17° 20'	50° 58'	20° 14'	13° 14'
321	27° 16'	38° 49'	45° 11'	15° 47'
552	33° 43'	31° 35'	47° 7'	19° 26'
331	37° 51'	26° 1'	46° 38'	22° 0'
772	40° 59'	22° 40'	40° 7'	23° 50'
441	43° 20'	20° 41'	45° 32'	25° 14'

TRAPICUBOONS.

Cf. Fig. 131.	Edge B 211, A 111, etc.	Edge C 211, A 112, etc.	Angle on a 100.	Angle on a 111.
411	27° 16'	60° 0'	19° 26'	36° 14'
722	30° 43'	55° 50'	22° 0'	32° 44'
311	35° 34'	50° 26'	25° 14'	29° 29'
522	40° 45'	45° 30'	26° 20'	25° 14'
211	46° 11'	33° 34'	35° 15'	19° 26'
322	58° 2'	19° 45'	43° 38'	11° 26'

HEXOCTAHEDRONS.

Cf. Fig. 132.	Edge A 321, A 312, etc.	Edge B 321, A 311, etc.	Edge C 321, A 312, etc.	Angle on a 100.	Angle on a 111.
421	17° 15'	25° 12'	35° 7'	29° 12'	28° 64'
531	27° 39'	19° 27'	27° 39'	32° 48'	28° 33'
321	21° 47'	31° 0'	21° 47'	36° 42'	22° 13'
432	45° 6'	43° 30'	15° 5'	42° 11'	15° 13'
411	32° 29'	23° 47'	15° 50'	39° 19'	25° 4'

* A fuller list is given in the Introduction to Dana's System of Mineralogy, 1892, pp. xx-xxiii.

2 PYRITOHEDRAL CLASS (2). PYRITE TYPE

(Dyakisidodecahedral, Pentagonal Hexahedral, Diploidal, or Tesseral Central Class)

71. Typical Forms and Symmetry. 3 xl. Ax.-2; 4 diag. Ax.-3; 3 xl. P.; C. — The typical forms of the pyritohedral class are the *pyritohedron* or pentagonal dodecahedron, Figs. 147-149, and the *trapezohedron* or dyakisidodecahedron, Fig. 153. The symmetry of these forms, as of the class as a whole, is as follows: The three crystallographic axes are axes of binary symmetry only. There are also four diagonal axes of triad symmetry converging with the octahedral axes. There are but three planes of symmetry, these coincide with the planes of the crystallographic axes and are parallel to the faces of the cube.

The stereographic projection in Fig. 146 shows the distribution of the faces of the general form, but diploidal, and thus exhibits the symmetry of the class. This should be carefully compared with the corresponding projection, Fig. 140, for the normal class in that the latter group of symmetry here present may be then again introduced. In studying the forms hereafter and illustrated in the following pages, this matter of symmetry, especially in relation to that of the normal class, should be continually kept in mind.

It will be observed that the faces of the *pyritohedron*, Fig. 147, are the faces of the cube (Fig. 139) are arranged in parallel pairs and on this account these forms have been sometimes called *parallel-hemihedrons*. For a few of these crystals we prefer to describe these forms as cubes when certain crystals type parallel-faced hemihedron or pentagonal hemihedron.

72. Pyritohedron. The *pyritohedron*, Fig. 147, is so named because it is a typical form with the common species, *pyrite*. It is a solid bounded



Pyritohedron



Showing the relation of the faces to the axes of symmetry.

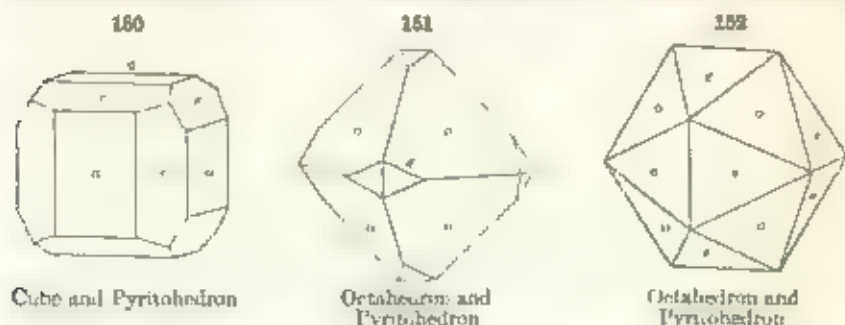
by twelve faces, one of which is a pentagon (Fig. 147) longer than the other four sides, edges of which are of equal length. The faces are arranged in parallel pairs and on this account these forms have been sometimes called *parallel-hemihedrons*. For a few of these crystals we prefer to describe these forms as cubes when certain crystals type parallel-faced hemihedron or pentagonal hemihedron.

The general symbol is $\{h k l\}$, where h, k, l are the indices of the faces of the cube. If we choose the faces of the cube as $112, 112\bar{1}, 210, 210\bar{1}, 011, 011\bar{1}$ (Fig. 147) then the general symbol for the pyritohedron is $\{210\}$, where $2, 1, 0$ are the indices of the faces of the cube.

plementary negative form* shown in Fig. 148; the symbol is here (120) (other common forms are (250), (240), (130), etc.)

The positive and negative pyritohedrons together embrace twenty-four faces, having the same position as the twenty-four face faces of the tetrahexahedron of the normal class. The relation between the tetrahexahedron and the pyritohedron is shown in Fig. 149, where the alternate faces of the tetrahexahedron (indicated by shading) are extended to form the faces of the pyritohedron.

73 Combinations. The faces of the pyritohedron replace the edges of the cube as shown in Fig. 150. It resembles Fig. 149 but here the faces



make unequal angles with the two adjacent cubic faces. On the other hand, when the pyritohedron is modified by the cube, the faces of the latter truncate the longer edges of the pentagons.

Fig. 151 shows the combination of the pyritohedron and octahedron, and in Fig. 152 these two forms are equally developed. The resulting combination bears a close similarity to the *icosahedron* or regular twenty-faced solid, of geometry. Here, however, of the twenty faces, the eight octahedral are equilateral triangles, the twelve others belonging to the pyritohedron are isosceles triangles.

74. Diploid. — The *diploid* is bounded by twenty-four similar faces, each meeting the axes at unequal distances, its general symbol is hence $\{hkl\}$, and common forms are $\{321\}$, $\{421\}$, etc. The form $\{321\}$ is shown in Fig. 153, the symbols of its faces, as given, should be carefully studied. As seen in the figure, the faces are quadrilaterals or trapeziums; moreover, they are grouped in pairs, hence the common name *diploid*. It is also sometimes called a *dyakisdodecahedron*.

The complementary negative form bears to the positive form of Fig. 153 the same relation as the negative to the positive pyritohedron. Its faces have the symbols $\bar{3}12$, $\bar{2}31$, $\bar{1}23$, in the front octant, and similarly with the proper negative signs in the others. The positive and negative forms together obviously embrace all the faces of the hexoctahedron of the normal class. The diploid can be considered to be

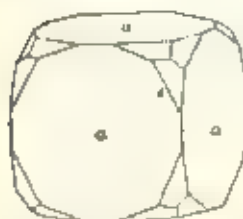


* The negative forms in this and similar cases have sometimes distinct letters, sometimes the same as the positive form, but are then distinguished by a subscript accent, as $\epsilon(240)$ and $\epsilon_1(240)$.

derived from the hexoctahedron by the extension of the alternate faces of the latter and the omission of the remaining faces, exactly as in the case of the pyritohedron and tetrahexahedron (Art. 72).

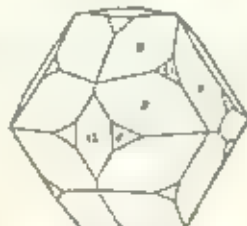
In Fig. 154 the positive diploid is shown in combination with the cube. Here the three faces replace each of its solid angles. This combination form

154

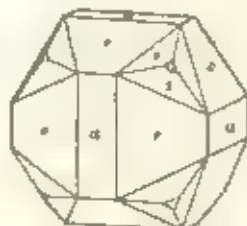


Cube and Diploid

155

Cube, Octahedron and
Diploid

156

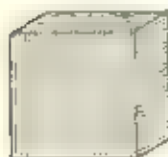
Cube, Diploid and
Pyritohedron

resembles that of Fig. 129, but the three faces are here unequally inclined upon two adjacent cubic faces. Other combinations of the diploid with the cube, octahedron and pyritohedron are given in Figs. 155 and 156.

75. Other Forms. If the pyritohedral type of symmetry be applied to pyrites each parallel to two of the axes, it is seen that this symmetry has for axis of three, and the resulting form is obviously a cube. This cube cannot be

distinguished geometrically from the cube of the normal class, but it has its own characteristic molecular symmetry. Corresponding to this it is common to find cubes of pyrite with fine lines (striations) parallel to the alternate edges, as indicated in Fig. 157. These are due to the partial development of pyritohedral faces (210). On a normal cube striae, if present, must be parallel to both sets of edges on each cubic face.

157



Pyrite. Striated Cube

Similarly to the cube, the remaining forms of this pyritohedral class, namely, (111), (110), (hkl), have the same geometrical form, respectively, as the octahedron, dodecahedron, the trisoctahedron and trapezohedron of the normal class. In molecular structure, however, these forms are distinct, each having the symmetry described in Art. 71.

76. Angles. — The following tables contain the angles of some common forms.

PYRITOHEDRONS

	Edge A	Edge C	Angle on	Angle on
cf. Fig. 147	210	210 A 110 etc	a 100	a 1
410	38° 41'	76° 23'	14° 21'	45° 33'
500	38 52	73 36	16 20	45 50
520	43 40	69 49	21 48	41 52
210	63 71	66 25	26 24	39 14
250	61 55	63 41	30 57	37 37
220	61 25	62 00	33 41	36 48
420	73 44	61 09	36 52	36 12
510	77 14	60 48	38 38	35 15
550	79 36	60 21	39 48	35 35

Tetrahedra.

Fig. 153.	321 A 321 etc.	321 A 321 etc.	321 A 321 etc.	Angle on a 100	Angle on c 111
421	31 45	25' 12"	49° 11'	20° 12'	25° 6'
532	36 14	27 6	35 20	15 47	27 30
531	60 54	10 25	19 27	32 8	28 43
551	63 36	12 6	53 55	32 30	31 34
521	64 37	31 0	34 12	37 42	32 12
432	67 42	43 36	90 17	37 1	13 13
431	72 4	22 37	43 3	38 10	25 4

3. TETRAHEDRAL CLASS (3) TETRAHEDRITE TYPE

(*Hextetrahedral, Tetrahedral Hemihedral, or Disesseral Polar Class*)

77. Typical Forms and Symmetry. 3 xl Ax.-2; 4 diag. Ax.-3; 6 diag. P.

The typical form of this class and that from which it derives its name, is the *tetrahedron*, shown in Figs. 159-160. There are also three other distinct forms, shown in Figs. 167-169.

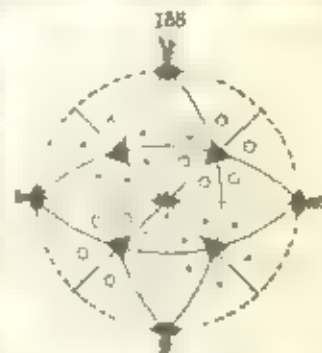
The symmetry of this class is as follows. There are three axes of binary symmetry which coincide with the crystallographic axes. There are also four diagonal axes of trigonal symmetry which coincide with the octahedral axes. There are six diagonal planes of symmetry. There is no center of symmetry.

The stereographic projection, (Fig. 158), shows the distribution of the faces of the general form {111}, hextetrahedron, and these exhibit the symmetry of the class. It will be seen at once that the like faces are all grouped in the *alternate octants*, and that will be seen to be characteristic of all the forms peculiar to this class. The relation between the symmetry here described and that of the normal class must be carefully studied.

In distinct from the pyritohedral forms whose faces were in parallel pairs, the faces of the tetrahedron and the analogous solids are inclined to each other, and hence they are sometimes spoken of as *inclined hemihedra*, and the type of so-called hemihedron here illustrated is then called *inclined or tetrahedral hemihedron*.

78. **Tetrahedron.** — The tetrahedron,* as its name indicates, is a four-faced solid, bounded by planes meeting the axes at equal distances. Its general symbol is {111} and the four faces of the positive form (Fig. 159) have the symbols 111, $\bar{1}\bar{1}1$, $1\bar{1}\bar{1}$, $\bar{1}1\bar{1}$. These correspond to four of the faces of the octahedron of the normal class (Fig. 111). The relation between the two forms is shown in Fig. 161.

Each of the four faces of the tetrahedron is an equilateral triangle; the (normal, interfacial) angle is $109^{\circ} 28' 16''$. The tetrahedron is the regular



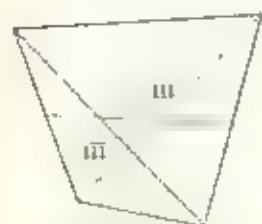
Symmetry of Tetrahedral Class

* This is one of the two types of which geometry shows that, with the cube, octahedron, the regular pentagonal dodecahedron, and the rhombicuboctahedron (the last two, as already noted, are impossible forms among crystals).

triangular pyramid of geometry, but crystallographically it must be so placed that the axes join the mid points of opposite edges, and one axis is vertical.

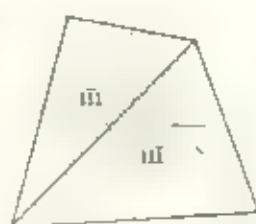
There are two possible tetrahedrons—the positive tetrahedron $\overline{111}$, designated by the letter o , which has already been described, and the negative

159



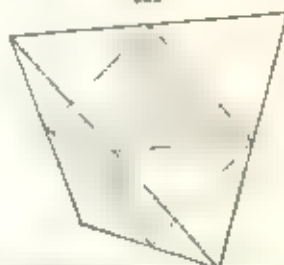
Positive Tetrahedron

160



Negative Tetrahedron

161



Showing Relation between Octahedron and Tetrahedron

tive tetrahedron, having the same geometrical form and symmetry but the indices of its four faces are $\overline{111}$, $\overline{111}$, $\overline{111}$, $\overline{111}$. This second form is shown in Fig. 160; it is usually designated by the letter o . These two forms are,

162



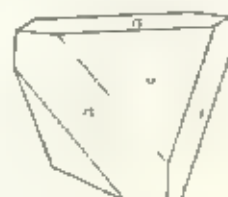
Positive and Negative Tetrahedrons

163



Cube and Tetrahedron

164



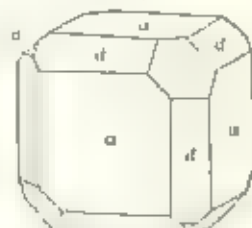
Tetrahedron and Cube

165



Tetrahedron and Dodecahedron

166



Borneo (Cube) Disintegration with Positive and Negative Tetrahedrons

as stated above, identical in geometrical shape, but they may be distinguished in many cases by the tests which serve to reveal the molecular structure, particularly the cleavage figures, and in many cases by pyroelectricity (see on pyroelectricity p. 335, Art. 460). It is probable that the positive and negative tetrahedrons of spinelites (see that species) have a constant differ-

ence in this particular, which makes it possible to distinguish them on crystals from different localities and of different age.

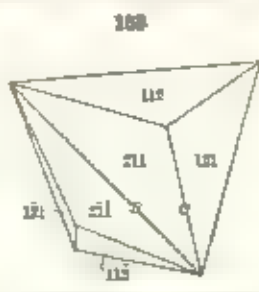
If both tetrahedrons are present together, the form in Fig. 162 results. This is geometrically an octahedron when the two forms are equally developed, but crystallographically it is always only a combination of two unlike forms: the positive and negative tetrahedrons, which can be distinguished as already noted.

The tetrahedron in combination with the cube replaces the alternate solid angles as in Fig. 163. The cube modifying the tetrahedron truncates its edges as shown in Fig. 164. The normal angle between adjacent cube and tetrahedral faces is $54^{\circ}44'$. In Fig. 165 the dodecahedron is shown modifying the positive tetrahedron, while in Fig. 166 the cube is the predominating form with the positive and negative tetrahedrons and dodecahedron.

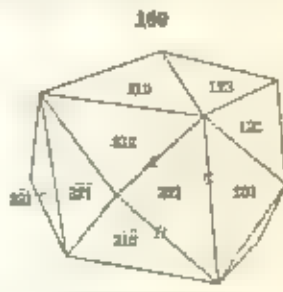
79. Other Typical Forms. There are three other distinct types of solids in this class, having the general symbols hkl , hll , and hkl . The first of these is shown in Fig. 167, here the symbol is $\{211\}$. There are twelve



Tetragonal Tristetrahedron



Trigonal Tristetrahedron



Hexitetrahedron

faces, each a quadrilateral, belonging to this form, distributed as determined by the tetrahedral type of symmetry. They correspond to twelve of the faces of the ~~isotetrahedron~~ ~~isotetrahedron~~, namely, all those falling in alternate octants. This type of solid is sometimes called a *tetragonal tristetrahedron*, or a *deltoid dodecahedron*. It does not occur alone among crystals, but its faces are observed modifying other forms.

There is also a complementary negative form, corresponding to the positive form, related to it in precisely the same way as the negative to the positive tetrahedron. Its twelve faces are those of the trisoctahedron which belong to the other set of alternate octants.

Another form, shown in Fig. 168, has the general symbol (hll) here (211) . It is bounded by twelve like triangular faces, distributed after the type determined by tetrahedral symmetry and corresponding consequently to the faces of the alternate octants of the form hll the *trapezohedron* of the normal class. This type of solid is sometimes called a *trigonal tristetrahedron* or *trikinnetrahedron**. It is observed both alone and in combination, espe-

* It is to be noted that the tetragonal tristetrahedron has faces which resemble those of the trapezohedron, tetragonal trisoctahedron, although it is related to the latter but to the trigonal tetrahedron, trigonal trisoctahedron. On the other hand, the faces of the trigonal tristetrahedron resemble those of the trisoctahedron, though in fact related to the trapezohedron.

cially with the species tetrahedrite, it is much more common than the form (hkl) . There is here again a complementary negative form. Fig. 170 shows the positive form $\pi(211)$ with the positive tetrahedron and Fig. 171 the form $\pi(311)$ with $a(100)$, $a(111)$, and $d(110)$. In Fig. 172 the negative form $\pi_1(2\bar{1}\bar{1})$ is present.

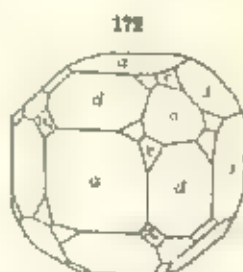
The fourth independent type of solids in this class is shown in Fig. 169. It has the general symbol (hki) , here (321) , and is bounded by twenty-four faces distributed according to tetrahedral symmetry, that is, embracing all the faces of the alternate octants of the forty-eight-faced hexoctahedron. This form is sometimes called a *hextetrahedron* or *herakitetrahedron*. The complementary negative form $(h\bar{k}\bar{i})$ embraces the remaining faces of the hexoctahedron. The positive hextetrahedron, $\pi(531)$ is shown in Fig. 172 with the cube, octahedron, and dodecahedron, also the negative trigonal tristetrahedron $\pi_1(2\bar{1}\bar{1})$.



Tetrahedrite



Sphalerite



Boracite

80. If the tetrahedral symmetry be applied in the case of planes each parallel to the two axes, it will be seen that there must be six such faces. They form a cube similar geometrically to the cube both of the normal and pyrohedron class but differing in its molecular structure, as can be readily proved, for example, by pyroelectricity (Art. 450). Similarly in the case of the planes having the symbol (110) , there must be twelve faces forming a rhombic dodecahedron bearing the same relation to the like geometrical form of the normal class. The same is true again of the planes having the position expressed by the general symbol (hki) ; there must be twenty-four of them and they together form a tetrahexahedron.

In this class, therefore, there are also seven types of forms, but only four of them are geometrically distinct from the corresponding forms of the normal class.

81. Angles. — The following tables contain the angles of some common forms.

TETRAHEDRAL TRISTETRAHEDRONS

Of Fig. 167	Edge A $\angle 211 \wedge 2\bar{1}\bar{1}$, etc.	Edge B $\angle 211 \wedge 2\bar{1}\bar{2}$, etc.	Angle on $a(100)$	Angle on $a(111)$
332	17° 34'	97° 54½'	60° 14½'	10° 11'
221	27° 36'	90° 0'	48° 1½'	10° 47½'
552	33° 33½'	84° 11'	47° 7½'	19° 35½'
331	37° 51½'	80° 55'	46° 30'	32° 0'

TRIGONAL TRITETRAHEDRONS.

Cf Fig. 168.	211	Edge B A 211 etc.	211	Edge C A 121, etc.	Angle on a 100	Angle on a 111
411		28° 50'		40° 0'	19° 28½'	35° 15½'
732		44 0		55 60	22 0	32 44
311		50 28		60 36	25 14½	29 29½
522		58 59		13 30	29 29½	25 14½
211		70 31		33 33	35 15	19 28½
322		80 37		19 46	43 13½	11 25½

HEXETETRAHEDRONS.

Cf Fig. 169.	321	Edge A A 312 etc.	321	Edge B A 312 etc.	321	Edge C A 231 etc.	Angle on a 100	Angle on a 111
531		27° 39½'		57° 7'		27° 39½'	32° 18½'	28° 33½'
321		21 47½		49 44		21 47½	36 42	22 12½
432		16 54		52 11		15 54	42 11	15 13½
431		32 12½		47 32½		15 50	38 19½	25 4

4 PLAGIOHEDRAL CLASS (4) CUPRITE TYPE

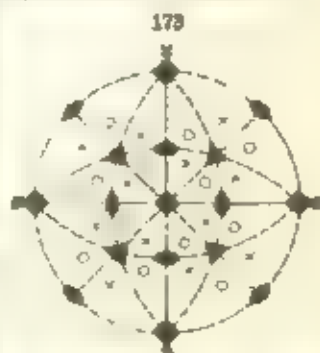
(*Pentagonal Icositetrahedral, Plagiohedral Hemihedral, Gyroidal, or Tesseral Holohedral Class*)

82. **Typical Forms and Symmetry.** 3 xl. Ax-4; 4 diag. Ax-3; 6 diag. Ax-2. The fourth class under the isometric system is called the plagiohedral or gyroidal class because the faces of the general form $\{hkl\}$ are arranged in spiral order. This is shown on the stereographic projection Fig. 173, and also in Figs. 174, 175, which represent the angle typical form of the class. These two complementary solids together embrace all the faces of the hexoctahedron. They are distinguished from one another by being called respectively right-handed and left-handed *peripentahedral icositetrahedrons*. The other forms of the class are geometrically like those of the normal class.

The symmetry characteristic of the class in general is as follows:

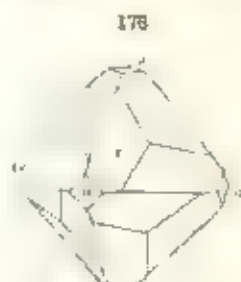
There are no planes of symmetry and no center of symmetry. There are, however, three axes of tetragonal symmetry normal to the cubic faces, four axes of trigonal symmetry normal to the octahedral faces, and six axes of binary symmetry normal to the faces of the dodecahedron. In other words, it has all the ~~axes~~ axes of symmetry of the normal class while without planes or center of symmetry.

83. It is to be noted that the two forms shown in Figs. 174, 175 are also geometrically, but are not superposable, in other words, they are related to one another as is a right- to a left-hand glove. They are hence said to be *enantiomorphous*, and, as explained elsewhere, the crystals belonging here may be expected to show circular polarization of light. It will be seen that the complementary positive and negative forms of the preceding classes, unlike those here, may be superposed by being rotated 90° about one of



Symmetry of Plagiohedral Class

the crystallographic axes. This distinction between positive and negative forms and between right- and left-handed enantiomorphous forms, exists also in the case of the classes of several of the other systems.



Right- and Left-handed Pentagonal Bipyramids

Cuprite

This class is rare among minerals; it is represented by cuprite and stannonite. It is usually shown by the distribution of the small modifying faces, or by the form of the etching figures. Fig. 176 shows a crystal of cuprite from Cornwall (Pratt), with the form $\pm\{111\} \cup \{112\}$.

5. TETARTOHEDRAL CLASS (5) ULLMANNITE TYPE

(Tetrahedral-Pentagonal Dodecahedra or Tesseral Polar Class)

84. Symmetry and Typical Forms. 3 xl. Ax. 2; 4 diag. Ax. 3. The fifth remaining possible class under the isometric system is illustrated by Fig. 178, which represents the twelve-faced solid corresponding to the general symbol hkl . The distribution of its faces is shown in the projection, Fig. 177. This form is sometimes called a *tetrahedral pentagonal dodecahedron*. It is seen to have one fourth as many faces as the form that in the normal class, hence there are four similar solids which together embrace all the faces of the hexoctahedron. These four solids, which are distinguished as right-handed, positive and negative, and left-handed, positive and negative, are enantiomorphous, like those of Figs. 174 and 175, and hence the sets crystallizing here may be expected to also show circular polarization. The remaining forms of the class are, besides the cube and the rhombicuboctahedron, the tetrahedron, the pyramidal, the tetragonal and trigonal tristetrahedrons, geometrically they are like the solids of the systems already described. This class has no plane of symmetry and no center of symmetry. There are three axes of binary symmetry normal to the cubic faces, and four axes of trigonal symmetry normal to the faces of the tetrahedron.

Symmetry of Tetartohedral Class

This group is illustrated by artificial crystals of barium nitrate, stron-



lain nitrate, sodium chlorate, etc. Further, the species ullmannite, which shows sometimes pyritohedra and again tetrahedral forms, both having the same composition, must be regarded as belonging here.



MATHEMATICAL RELATIONS OF THE ISOMETRIC SYSTEM

85. Most of the problems arising in the isometric system can be solved at once by the right-angle trigonometry of a sphere of projection (Fig. 42) without the use of any special formulae.

As it is readily seen that the angle between a cube face, as 100, and the adjacent face, as tetrahedron, 111, 112, 113, etc., can be obtained at once, since the tangent of this angle is equal to $\frac{1}{\sqrt{3}}$, or in general $\frac{k}{h}$,

$$\tan (\angle 100 \wedge 111) = \frac{k}{h}$$

$$ac = k = 1$$

$$bc = h = \sqrt{3}$$

$$\angle acb = 30^\circ$$

$$\tan \angle abc = \frac{ac}{bc} = \frac{k}{h} = \frac{1}{\sqrt{3}}$$

$$\angle abc = 30^\circ 34'$$

This relation is illustrated in Fig. 180, which also shows the method of graphically determining the indices of a tetrahedron, the angle between one of its faces and an adjacent cube face being given.

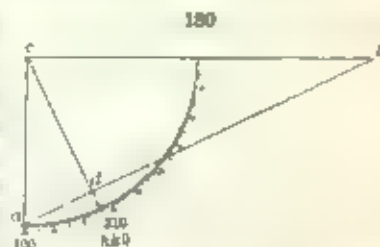
Since all the forms of a given crystal have the same angles, the indices of angles of crystals given in any set of

forms can be put in place may be determined unambiguously from the numbers, or, if more than one, by the formulas given in the following table.

86. Formulas. 1. The distance of the pole of any face hkl from the vertical axis of symmetry is $\frac{h^2 + k^2 + l^2}{2l}$. 2. The distance of the pole of any face hkl from the vertical axis of symmetry is $\frac{h^2 + k^2 + l^2}{2l}$. 3. The distance of the pole of any face hkl from the vertical axis of symmetry is $\frac{h^2 + k^2 + l^2}{2l}$.

These relations admit of much simplification in the various special cases, for $\angle 100 \wedge 111$:

$$\cos^2 P/a = \frac{h^2}{h^2 + k^2 + l^2}, \quad \cos^2 P/b = \frac{k^2}{h^2 + k^2 + l^2}, \quad \cos^2 P/c = \frac{l^2}{h^2 + k^2 + l^2}$$



(2) The distance between the poles of any two faces P and Q is given by the following equation, which in special cases may also be more or less simplified.

$$\cos PQ = \frac{Ap + kq + br}{\sqrt{h^2 + k^2 + p^2} \sqrt{q^2 + r^2 + b^2}}$$

(3) The calculation of the supplement interfacial or normal angles for the several forms may be accomplished as follows.

Tetrahedron The angles A and B are, as before, the supplements of the interfacial angles of the edges lettered as in Fig. 125.

$$\cos A = \frac{h^2 + 2kl}{2h^2 + l^2}, \quad \cos B = \frac{2h^2 + l^2}{2kl + l^2}$$

For the tetragonal-tetrahedron (Fig. 117), $\cos B = \frac{h^2 + 2kl}{2h^2 + l^2}$

Trigonal-tetrahedron (Fig. 131) B and C are the supplement angles of the edges as lettered in the figure.

$$\cos B = \frac{h^2}{h^2 + 2l^2}, \quad \cos C = \frac{2hl + l^2}{h^2 + 2l^2}$$

For the trigonal-tetrahedron (Fig. 133), $\cos B = \frac{h^2 + 2l^2}{h^2 + 2l^2}$

Tetrahedron (Fig. 122)

$$\cos A = \frac{h^2}{h^2 + k^2}, \quad \cos C = \frac{2kl}{h^2 + k^2}$$

For the pyritohedron (Fig. 147), $\cos A = \frac{h^2 - k^2}{h^2 + k^2}, \quad \cos C = \frac{hk}{h^2 - k^2}$

Hexoctahedron (Fig. 140).

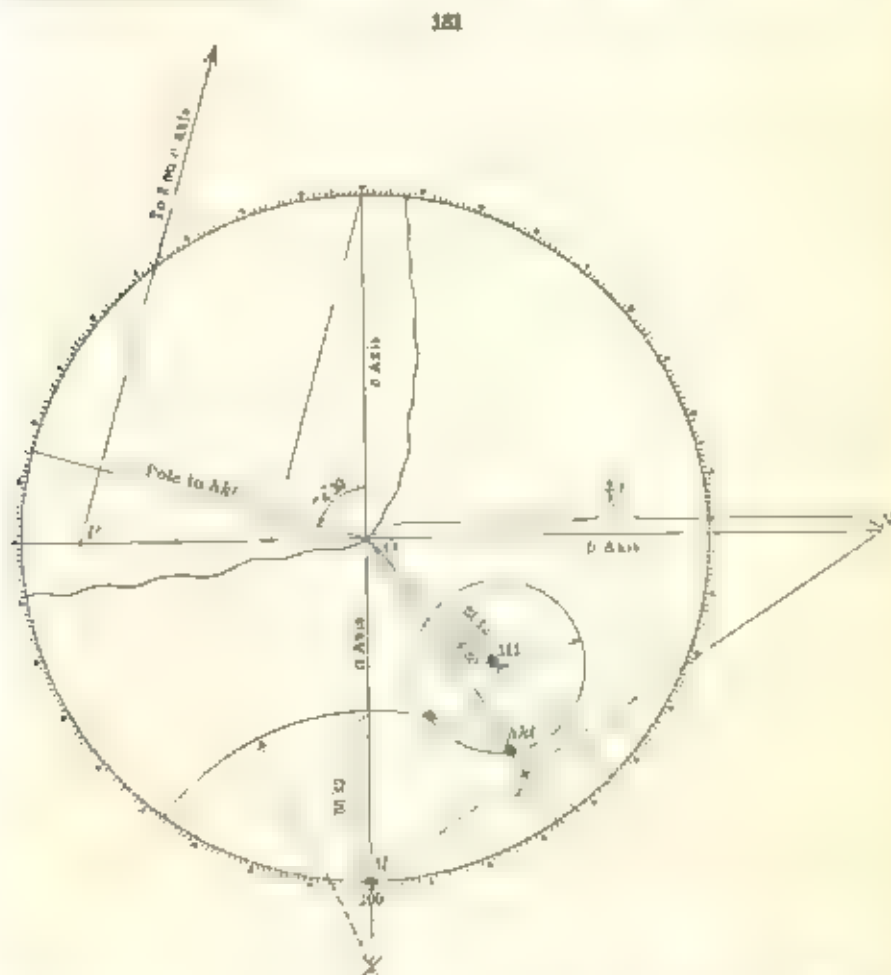
$$\cos A = \frac{h^2 + 2kl}{h^2 + k^2 + l^2}, \quad \cos B = \frac{h^2 + k^2 - l^2}{h^2 + k^2 + l^2}, \quad \cos C = \frac{2kl + l^2}{h^2 + k^2 + l^2}$$

For the dodecahedron (Fig. 153), $\cos A = \frac{h^2 + k^2 + l^2}{h^2 + k^2 + l^2}, \quad \cos C = \frac{kl + l^2 + h^2}{h^2 + k^2 + l^2}$

For the hexitetrahedron (Fig. 160), $\cos B = \frac{h^2 + 2kl}{h^2 + k^2 + l^2}$

87. To determine the indices of any face hkl of an isometric form, given the position of its pole on the stereographic projection. As an example of this problem the hexoctahedron 321 has been taken. It is assumed that the angles $111 \wedge 321 = 36^\circ 42'$ and $111 \wedge 321 = 22^\circ 12'$ are given. The method by which the desired pole is located from these measurements have been described on page 53 and are illustrated in Fig. 181. Having located the pole hkl on the σ -axis and drawn through it from the center C of the projection. This line OP represents the intersection with the horizontal plane which is the plane of the horizontal crystal face, is a line of a plane which is normal to the crystal face hkl . Since two planes which are at right angles to each other will intersect a third plane in lines that are at right angles to each other, it follows that the plane of the hexoctahedral face will intersect the plane of the horizontal axes at a line at right angles to OP . If therefore, the distance CP be taken as representing one of the a axes and the line $MP-N$ be drawn at right angles to OP , the distance $OM-N$ will represent the intercept of the face in question upon the c -axis. $OM-N$ is equal in this case to be $1/2$ of OP a value. The intercepts upon the two horizontal axes are, therefore, $1/2$. The plotting of the intercept upon the c -axis is shown in the upper left-hand quadrant of the figure. The angular distance from O to the pole hkl is measured by the stereographic protractor as $74^\circ 30'$. This angle is then laid off from the line representing the c -axis and the line representing the pole hkl is drawn. The distance CP is transferred from the lower part of the figure. Then we can construct the right triangle, the vertices of which is the c -axis, the horizontal axis is thus line OP , the intersection of the plane which is normal to the crystal face with the horizontal plane, and the hypotenuse is a line lying in the face and therefore at right angles to the pole of the face. This line would intersect the c -axis

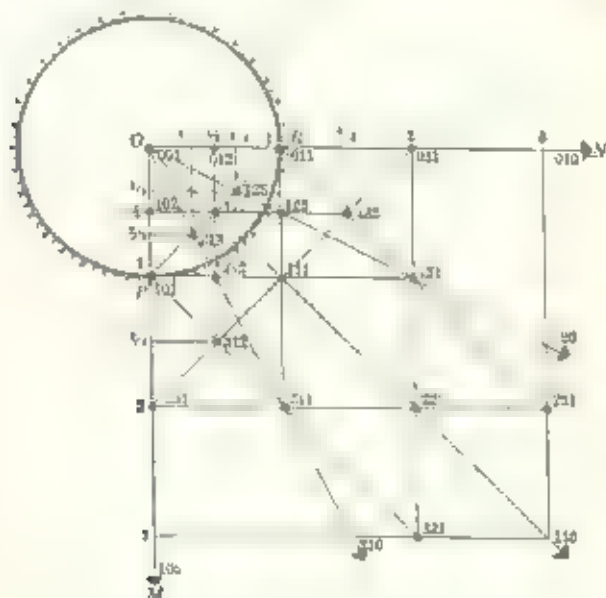
at a distance equal to $3C/4$. The same relation may be shown by starting this last one from a point on the x axis which is at a distance from the center of the figure equal to $C/4$. In this case, by a triangle on the horizontal line OP would be one third the total length. If these constructions the parameters of the four in question are shown to be $1a$, $1b$, $3c$, giving (321) as its indices.



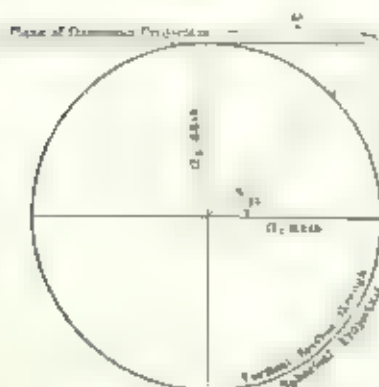
88. To determine the indices of the faces of isometric forms, given the positions of their poles on the gnomonic projection. As an example, let us assume that the faces right-hand and left-hand of the gnomonic projection of isometric forms, Fig. 24, have been taken, and represented in Fig. 182. The axes $O-M$ and $O-N$ are at right angles to each other and may represent the horizontal crystallographic axes a and b , and O from which pole of the projection faces are drawn perpendicular lines (these axes are indicated) will be seen that the c exception made upon them (you have rational numbers to each other). And now we are dealing with the isometric system in which the crystallographic axes are all of one and interchangeable with each other, it follows that the different interpoles upon $O-M$ and $O-N$ are identical. The distance $O-E$ (i.e. the distance from the center to the

43rd point of the projection must on the unit length of the axes. That this is true is readily seen by the construction of Fig. 183. The intercepts of the lines drawn from the different poles to the lines OY and $O'X$ are found to be $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, $\frac{1}{5}$, $\frac{1}{6}$, $\frac{1}{7}$, and $\frac{1}{8}$ of a unit distance. To find the Miller indices of any face represented, it is only necessary to

182



183



take the intercepts of the two lines drawn from its pole upon the two axes a and a' , place these values in their proper order and add a 1 as a third figure in a line, if necessary clear of fractions. Take for example the hexagonal prism $\{100\}$ as an area. The line drawn from its pole to intercept the axes at $\frac{1}{2}$ and $\frac{1}{3}$, which gives the expression $\frac{1}{2} \frac{1}{3} 1$, which, again, on clearing of fractions, yields 312, the indices of the face in question. In the case

of a face parallel to the vertical axis, the pole of which lies at infinity on the gnomonic projection, the h line may be obtained by taking any point on the radial line that points to the position of the pole and drawing perpendiculars to or lines representing the two horizontal axes. The negative intercepts formed upon these axes will give the first two numbers of the required indices while the third number will necessarily be 1.

II. TETRAGONAL SYSTEM

88. The tetragonal system includes all the forms which are referred to three axes at right angles to each other of which the two horizontal axes are equal to each other in length and interchangeable and the third, the vertical axis, is either shorter or longer. The horizontal axes are designated by the letter a , the vertical axis by c (see Fig. 184). The length of the vertical axis expresses properly the axial ratio of $a : c$, a being uniformly taken as equal to unity. The axes are orientated and their opposite ends designated by plus and minus signs exactly as in the case of the isometric system.

Seven classes are embraced in this system. Of these the normal class is common and important among minerals, two others have several representatives, and another a single one only. It may be noted that in four of the classes the vertical axis is an axis of tetragonal symmetry, in the remaining three it is an axis of binary symmetry only.

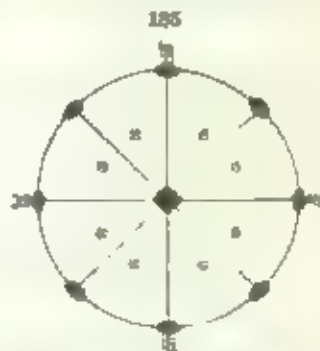
1. NORMAL CLASS (6) ZIRCON TYPE

(*Ditetragonal Dipyramid, Holohedral or Ditetragonal Equatorial Class*)

90. **Symmetry.** Vert. Ax.-4; 4 hor. Ax.-2; hor. P; 4 vert. P.; C. The forms belonging to the normal class of the tetragonal system (cf. Figs. 188 to 210, have one principal axis of tetragonal symmetry (whence name of



Axes of Tetragonal Mineral,
Orthoclase $a = 1.7x$

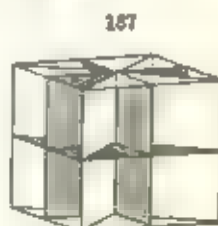
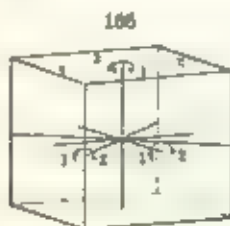


Symmetry of Normal Class
Tetragonal System

the system, which coincides with the vertical crystallographic axis c . There are also four horizontal axes of binary symmetry, two of which coincide with the horizontal crystallographic axes while the other two are diagonal axes bisecting the angles between the first two.

Further, they have one principal plane of symmetry, the plane of the horizontal crystallographic axes. There are also four vertical planes of symmetry which pass through the vertical crystallographic axis c and make angles of 45° with each other. Two of these latter planes include the horizontal crystallographic axes and are known as *axis* planes of symmetry. The other two are known as *diagonal* planes of symmetry.

The axes and planes of symmetry are shown in Figs. 186 and 187.



Symmetry of Normal Class, Tetragonal System

The symmetry and the distribution of the faces of the general form, hkl , is shown in the stereographic projection, Fig. 185.

91. Forms — The various possible forms under the normal class of this system are as follows:

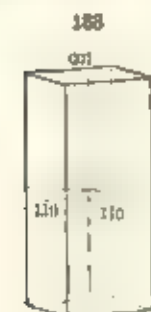
	Symbols
1 Base or basal pinacoid	(001)
2 Prism of the first order	(110)
3 Prism of the second order	(100)
4 Ditetragonal prism	(hro) as, (310), (210), (320), etc.
5 Pyramid of the first order	(hkl) as, (223), (111), (221), etc.
6 Pyramid of the second order	(hok) as, (203), (101), (201), etc.
7 Ditetragonal pyramid	(hkl) as, (421), (321), (122), etc.

92. Base or Basal Pinacoid. The *basal* is that form which includes the two similar faces which are parallel to the plane of the horizontal axes. These faces have the indices 001 and 00 $\bar{1}$ respectively. It is an "open form" as they do not include a space, consequently this form can occur or it in combination with other forms. Cf. Figs. 188-191, etc. This form is always lettered c in this work.

93. Prisms. — Prisms in systems other than the isometric have been defined to be forms whose faces are parallel to the vertical axis c of the crystal, while they meet the two horizontal axes. In this system the four-faced form whose planes are parallel both to the vertical and one horizontal axis is also called a prism. There are hence three types of prisms here included.

94. Prism of First Order. The *prism of the first order* includes the four faces which, while parallel to the vertical axis, meet the horizontal axes at equal distances, its general symbol is consequently (110). It is a *square prism*, with interfacial angles of 90° . It is shown in combination with the base in Fig. 188. It is usually designated by the letter m . The indices of its faces, taken in order, are 110, $\bar{1}10$, 110, $\bar{1}10$.

95. Prism of Second Order. — The prism of the second order shown* in combination with the base in Fig. 189 includes the four faces which are parallel at once to the vertical and to a horizontal axis. It has, therefore, the general symbol, $\{100\}$. It is a square prism with an angle between any two adjacent faces of 90° . It is uniformly designated by the letter *a*, and its faces, taken in order, have the indices $100, 010, \bar{1}00, 0\bar{1}0$.



First Order Prism



Second Order Prism



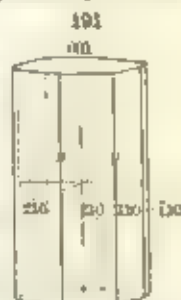
First and Second Order Prisms

It will be seen that the combination of this form with the base is the analogue of the cube of the isometric system.

The faces of the prism of the first order truncate the edges of the prism of the second order and vice versa. When both are equally developed, as in Fig. 190, the result is a regular eight-sided prism, which, however, it must be remembered is a combination of two distinct forms.

It is evident that the two prisms described do not differ geometrically from one another, and furthermore, in a given case the symmetry of this class allows either to be made the first order, and the other the second order prism according to the position assumed for the horizontal axes. If on crystals of a given species both forms occur together equally developed (or, on the other hand, separately on different crystals, and without other faces than the base, there is no means of telling them apart unless by minor characteristics, such as striations or other markings on the surface, etchings, etc.

96. Ditetragonal Prism. The ditetragonal prism is the form which is bounded by eight similar faces, each one of which is parallel to the vertical axis and *c* meeting the two horizontal axes at unequal distances. It has the general symbol $\{hk0\}$. It is shown in Fig. 191, where $\{hk0\} = \{210\}$.



Ditetragonal Prism

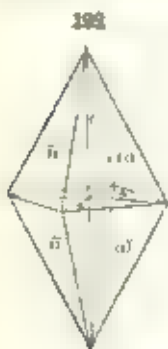
* In Figs. 188-191 the dimensions of the form are made to correspond to the assumed length of the vertical axis, here $c = 1.74$ as in calcite, used in Fig. 204. It must be noted, however, that in the case of actual crystals of these forms, while the tetragonal symmetry is usually indicated by the visible physical character of the face *c*, no comparison with the faces *a*, *m*, etc., in the vertical prismatic zone, no *terminations* can be drawn as to the relative length of the vertical axis. This fact can be ascertained only when a pyramid is present, it is fixed for the species when a particular pyramid is chosen as the fundamental or unit form, as explained later.

The successive faces have here the indices 210, 120, $\bar{1}20$, $\bar{2}10$, $\bar{3}10$, 120, 120, $\bar{1}20$.

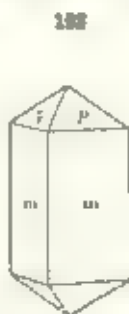
In Fig. 203 a combination is shown of this form ($h = 310$) with the second order prism, the edges of which it bevels. In Fig. 207 ($h = 210$) it bevels the edges of the first order prism m . In Fig. 208 ($h = 310$), it is combined with both pairs of prisms.

97. Pyramids. There are three types of pyramids in this class, corresponding respectively to the three prisms which have just been described. As already stated, the *third order pyramid* is given in systems other than the isometric to a form whose planes meet all three of the axes, in this system the form whose planes meet the axis c and one horizontal axis while parallel to the other is also called a pyramid. The pyramids of this class are strictly *triple pyramids*, *bipyramids* or *dipyramids* of some authors.

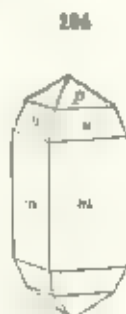
98. Pyramid of First Order.—A pyramid of the *first order* is a form whose eight similar faces intersect the two horizontal axes at equal distances and also intersect the vertical axis. It has the general symbol, hka . It is a *square pyramid* with equal interfacial angles over the similar edges, and the faces replace the horizontal or basal, edges of the first order prism and the small angles of the second order prism. If the ratio of the vertical to the horizontal axis for a given first order pyramid is the assumed axial ratio for the species, the form is called the *fundamental form*, and it has the symbol 111 , as in Fig. 192. The indices of its faces given in order are Above 111 , $\bar{1}11$, $\bar{1}\bar{1}1$, below $1\bar{1}1$, $1\bar{1}\bar{1}$, $\bar{1}\bar{1}\bar{1}$.



First Order
Pyramid



Zircon, First Order
Prism and Pyramid



Zircon, First Order
Prism and Pyramid



Pyroxene, Second
Order Prism and
First Order Pyramid

Obviously the angles of the first order pyramid—and hence its geometrical aspect—vary widely with the length of the vertical axis. In Figs. 192 and 193, the pyramids shown have in both cases the symbol 111 but in the first case the axial ratio $c = 1.78$, while in the second $c = 0.64$.

For a given species there may be a number of first order pyramids, varying in position according to the ratio of the intercepts upon the vertical and horizontal axes. Their symbols, passing from the base 001 to the first prism 110 , may thus be (111) , (112) , (113) , (114) , (115) , (116) , (117) , (118) , (119) , (11∞) , etc. In the general symbol of these forms hka , as k diminishes the form approaches more and more nearly to the base (001) , for which $k = 0$,

as h increases, the form passes toward the first order prism. In Fig. 194 two pyramids of this order are shown, $p(111)$, and $a(3s1)$.

99. **Pyramid of Second Order.**—The pyramid of the second order is the form Fig. 196 whose faces are parallel to one of the horizontal axes, while meeting the other two axes. The general symbol is $(h0l)$. These faces replace the basal edges of the second order prism Fig. 197, and the solid angles of the first order prism (cf. Fig. 193). It is a *square pyramid* since its basal section is a square, and the interfacial angles over the four terminal edges, above and below, are equal. The successive faces of the form (101) are as follows: Above 101 , 011 , 101 , 011 , below $10\bar{1}$, $01\bar{1}$, $10\bar{1}$, $01\bar{1}$.

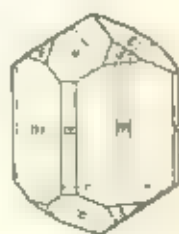
196

Second Order
Pyramid

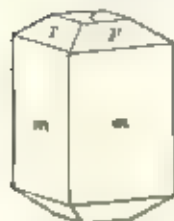
197

Second Order Prism
and Pyramid

198

But in First and Second Order
Prisms and Pyramids

199

Vesuvianite
First Order Prism,
Pyramid and Base

200

Vesuvianite
First and Second Order
Prisms

201

Cassiterite
First and Second Order
Pyramids

If the ratio of the intercepts on the horizontal and vertical axes is the assumed axial ratio of the species, the symbol is (101) and the form is designated by the letter c . This ratio can be deduced from the measurement of either one of the interfacial angles γ or ϵ (Fig. 196) over the terminal or basal edges, as explained later. In the case of a given species, a number of second order pyramids may occur, varying in the ratio of the intercepts on the axes a and c . Hence there is possible a large number of such forms whose symbols may be for example, (104) , (103) , (102) , (101) , (302) , (201) , (301) , etc. These mentioned first come nearest to the base (001) , those last to the second order prism (100) , the base is therefore the limit of these pyramids $(h0l)$ when $h = 0$, and the second order prism (100) when $h = 1$ and $l = 0$. Fig. 204 shows the three second order pyramids $a(105)$, $c(101)$, $p(201)$.

A second order pyramid truncating the pyramidal edges of a given first

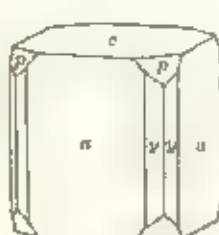
order pyramid as in Fig. 201 has the *same* ratio as it has for h to l . Thus 101 truncates the terminal edge of $\{111\}$ (201) of $\{221\}$, etc. This is obvious because each face has the same position as the corresponding edge of the other form (see Fig. 201, when $s = 111$ and $e = 101$, *also* Figs. 204, 208, where $r = 115$ $u = 105$). Again, if a first order pyramid truncates the

203



Vesuvianite
First and second Order
Pyramids, First Order Pyr-
amid and Base

202



Apophyllite
Second Order Prism, Dite-
trapezoidal Prism, First
Order Pyramid and Base

204



Octahedrite
Two First Order Pyr-
amids, First Order Prism,
Three Second Order
Pyramids and Base

pyramidal edges of a given second order pyramid, its ratio for h to l is half that of the other form, that is, $\{112\}$ truncates the pyramidal edges of $\{101\}$, $\{111\}$ of 201 etc. This relation is exhibited by Fig. 204 where $p\{111\}$ truncates the edges of $q\{201\}$. In both cases the zonal equations prove the relations stated.

100. Ditetragonal Pyramid. - The *ditetragonal pyramid*, or double eight-sided pyramid, is the form each of whose sixteen similar faces meets the

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Ditetragonal
Pyramid

208



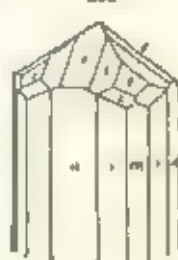
Zircon
First and Second Order
Pyramids, First Order
Pyramid, Ditetrag-
onal Pyramid

207



Cassiterite

205



Rutile

three axes at unequal distances. This is the most general case of the symbol (hkl) where h , k , l are all unequal and no one is equal to 0. That there are sixteen faces in a single form is evident. Thus for example, for the form $\{212\}$ the face 212 is similar to 122 , the two lateral axes being equal (not,

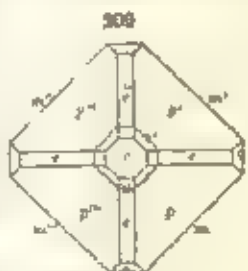
however, to 221). Hence there are two like faces in each octant. Similarly the indices of all the faces in the successive octants are, therefore, as follows:

Above	212	122	$\bar{1}\bar{2}\bar{2}$	$\bar{2}\bar{1}\bar{2}$	$\bar{2}\bar{1}\bar{2}$	$\bar{1}\bar{2}\bar{2}$	122	2 $\bar{1}\bar{2}$
Below	21 $\bar{2}$	12 $\bar{2}$	$\bar{1}\bar{2}2$	$\bar{2}\bar{1}2$	$\bar{2}\bar{1}2$	$\bar{1}\bar{2}2$	122	212

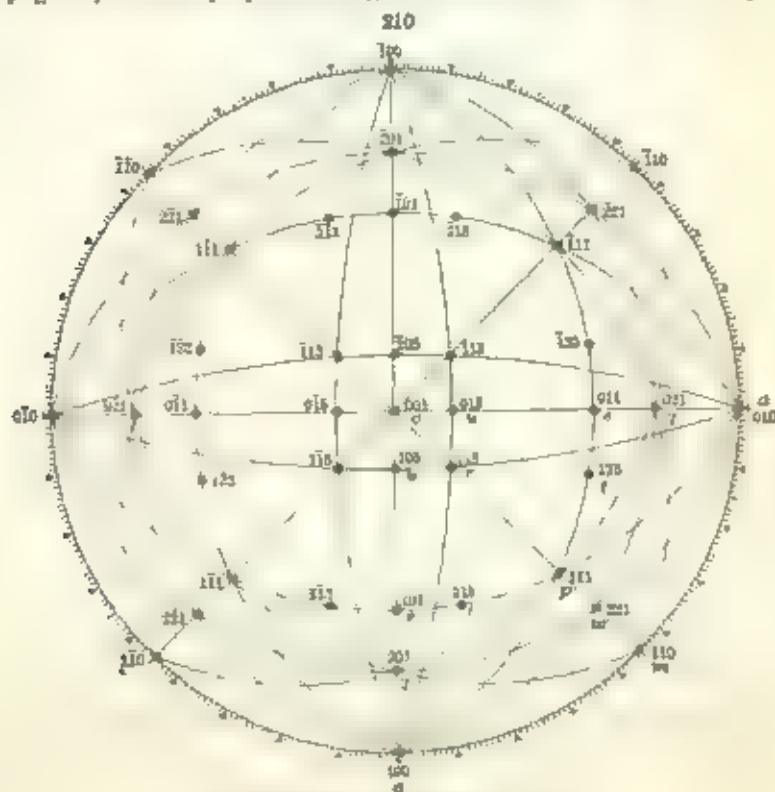
The ditetragonal pyramid 21 $\bar{2}$, is given in the above example instead of the (211) form because it lies in the *and* pyramid zone between the first and second order unit pyramids, (111) and (101), and its indices are to be obtained by the addition of the indices of these two forms, as (111) + (101) = (212).

This form is common with the species zircon, and is hence often called a *zirconoid*. It is shown in Fig. 205. It is not observed alone, though sometimes, as in Figs. 206 ($x = 311$) and 207 ($x = 321$), it is the predominating form. In Fig. 208 two ditetragonal pyramids occur, namely, $h31\bar{3}$ and $z321$.

101. In addition to the perspective figures already given, a basal projection (Fig. 209, is added

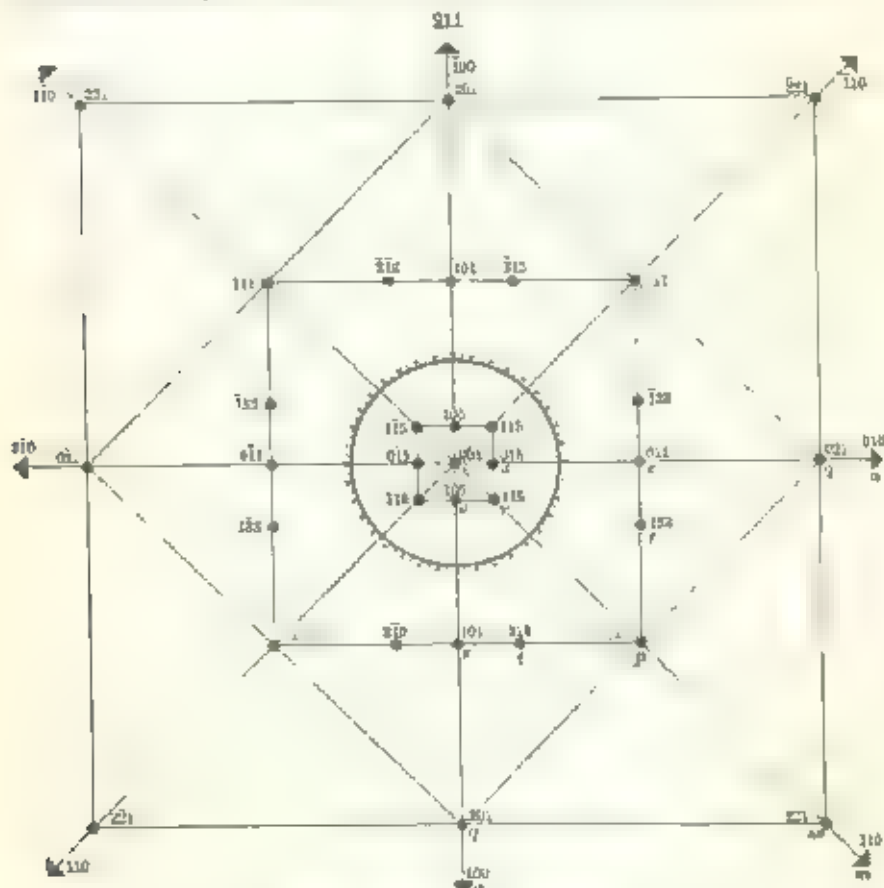


Octahedrite



Stereographic Projection of Octahedrite

of the crystal of octahedrite already referred to (Fig. 201), also stereograph (Fig. 210) and gnomonic (Fig. 211) projections of the same with the faces of the forms $\{221\}$ and $\{313\}$ added. These exhibit well the general relations of the normal class of the tetragonal system. The symmetry here is to be noted, first with respect to the similar zones $100, 001, \bar{1}00$ and $010, 001, 00\bar{1}$, also, and the other pair of similar zones, $110, 001, \bar{1}10$, and $\bar{1}10, 001, 110$.



Gnomonic Projection of Octahedrite

2. HEMIMORPHIC CLASS (7) 100SUCCINIMIDE TYPE

(*Tetragonal Pyramidal, Holohedral Hemimorphic, or Ditetragonal Polar Class,*

102 Symmetry Vert. A_2-4 , 4 vert. P—This class differs from the normal class in having no horizontal axes or plane of symmetry; hence the forms are hemimorphic as defined in Art. 23. It is not known to be represented among minerals, but is shown on the crystals of 100succinimide.

Its symmetry is illustrated by the stereographic projection (Fig. 212). Here the two *enantiomorphs* or *pechels* of the *enantiomorphs*, *hkl* and *hkl*, the *prisms* and *pyramids* differ geometrically from those of the *normal class*, though distinguished by their *crystallographic structure*, further, the *prisms* and *pyramids* are *double pyramids*. and each form is represented by one half of Figs. 192-196, 205 of Fig. 41 p. 24. There are hence six *crystallographic forms*, corresponding to the *upper and lower halves* of the first and second order pyramids and the *tetragonal pyramids*.

3. TRIPYRAMIDAL CLASS (8). SCHEELITE TYPE

(*Tetragonal Dipyramidal Pyramidal Hemihedral, or Tetragonal Equatorial Class*)

103. Typical Forms and Symmetry. Vert. Ax. 4, hor. P; C. The forms here included have one plane of symmetry only, that is the horizontal crystallographic axis, and one axis of tetragonal symmetry (the vertical crystallographic axis) normal to it. The *characteristic forms* are the *tetragonal prism* (*hkl*) and *pyramid* (*hkl*) of the *third order*, shown in Figs. 214, 215.

The stereographic projection (Fig. 213) exhibits the symmetry of the class and the distribution of the faces of the *general form* (*hkl*). Comparing this as well as the figures immediately following with those of the *normal class*, it is seen that this class differs from it in the absence of the vertical planes of symmetry and the horizontal axes of symmetry.

104. Prism and Pyramid of the Third Order.

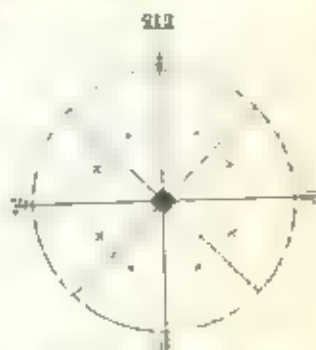
— The typical forms of this class are above stated, are a *square prism* and a *square pyramid* which are distinguished respectively from the *square prism* of 100 and *pyramid* of 110, shown in Figs. 198 and 199, and from the *square pyramids* (*hkl*) and (*hkl*) of Figs. 192 and 196 by the name *third order*.

The *third order prism* and *pyramid* may be considered as derived from the *tetragonal forms* of the *normal class* by using only one half the faces of the latter and the omission of

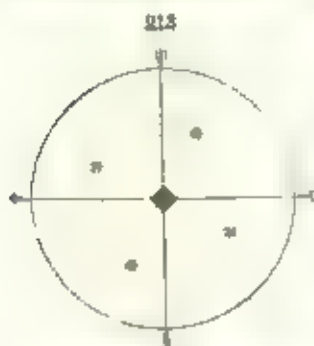
the remaining faces. There are therefore two complementary forms in each case, designated *left* and *right* which together include all the faces of the *tetragonal prism* (Fig. 191) and *tetragonal pyramid* (Fig. 205) of the *normal class*.

The indices of the faces of the two complementary prisms, as (210), are

Left. 210, 120, 210, 120.
Right. 120, 210, 120, 210.



Symmetry of Hemihedral Class



Symmetry of Tripyramidal Class

The indices of the faces of the corresponding pyramids, as (212), are

Left	above 212,	122,	$\bar{2}\bar{1}2$,	132,	below 212	123,	$\bar{2}\bar{1}3$,	122
Right	above 122,	$\bar{2}\bar{1}2$,	122,	212;	below 122	$\bar{2}\bar{1}2$,	122,	$\bar{2}\bar{1}2$

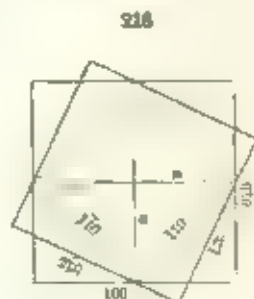
Fig. 210 gives a transverse section of the prisms $a(100)$ and $m(110)$, also the prism of the third order (120). Figs. 214, 215 show the right prism (120) and pyramid (122), of the third order.



Third Order Prism



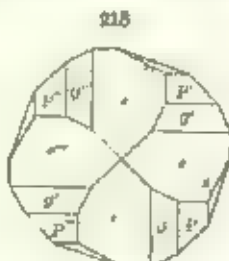
Third Order Pyramid



105. Other Forms. — The other forms of this class, that is, the base $a(001)$, the other square prisms $a(100)$ and $m(110)$, also the square pyramids $h(01)$ and $\bar{h}(0\bar{1})$ are geometrically like the corresponding forms of the normal class already described. The class shows therefore three types of square pyramids and hence is called the *tetrapyratidal class*.



Selenite



Scheelite



Meissite

106. To this class belongs the important species *scheelite*, also the isomorphous species *selenite* and *powellite*, unless it be that they are rather to be classed with *wulfenite* p. 101. Fig. 217 shows a typical crystal of *scheelite*, and Fig. 218 a basal section of one similar, these illustrate well the characteristics of the class. Here the forms are $a(101)$, $p(111)$, and the third order pyramids $g(212)$, $s(131)$. Fig. 219 represents a meissite crystal with $a(111)$, and the third order pyramid $s(111)$. See also Figs. 221, 222, in which the third order prism is shown.

The forms of this class are sometimes described (see Art. 27) as showing *pyramidal hemihedrism*.

4. PYRAMIDAL-HEMIMORPHIC CLASS (9) WULFENITE TYPE

(Tetragonal Pyramidal, Hemihedral Hemimorphic, or Tetragonal Polar Class)

107. **Symmetry.** **Vert. Ax.-4.** The fourth class of the tetragonal system is closely related to the class just described. It has the same vertical axis of tetragonal symmetry, but there is no horizontal plane of symmetry. The forms are, therefore, hemimorphic in the distribution of the faces (cf. Fig. 220). The species wulfenite of the Scheelite Group among mineral species probably belongs here, although the crystals do not always show the difference between the pyramidal faces, above and below, which would characterize distinct complementary forms. Figs. 221, 222, could, therefore, serve as illustrations of the preceding class, but in Fig. 223 a characteristic distinction is exhibited. In these figures the forms are $w(10\bar{2})$, $c(101)$, $n(111)$, also $f(210)$, $k(210)$, $s(432)$, $z(311)$.



221

222

223



Wulfenite

5. SPHENOIDAL CLASS (10) CHALCOPYRITE TYPE

(Tetragonal Sphenoidal, Sphenoidal Hemihedral, Didigonal Scalenohedral, or Ditetragonal Alternating Class)

108. **Typical Forms and Symmetry.** **3 xl. Ax.-2, 2 vert. diag. P.** — The typical forms of this class are the sphenoidal (Fig. 225) and the tetragonal scalenohedron (Fig. 226). They and all the combinations of this class show the following symmetry. The three crystallographic axes are axes of binary symmetry and there are two vertical diagonal planes of symmetry.

This symmetry is exhibited in the stereographic projection (Fig. 224), which shows also the distribution of the faces of the general form hkl . It is seen here that the faces are present in the alternate octants only, and it will be remembered that this same statement was made of the tetrahedral class under the isometric system. There is hence a close analogy between

these two classes. The symmetry of this class should be carefully compared with that of the first and third classes of this system already described.

109. Sphenoid. The *sphenoid*, shown in Fig. 225 is a four-faced solid, resembling a tetrahedron, but each face is an isosceles, not an equilateral triangle. It may be considered as derived from the first order pyramid of the normal class by the development of only the alternate faces of a latter. There are therefore possible two complementary forms known as the positive and negative sphenoids. The general symbol of the positive unit sphenoid is $\{111\}$, and its faces have the indices $111, \bar{1}\bar{1}\bar{1}, \bar{1}\bar{1}1, 11\bar{1}$ while the negative sphenoid has the symbol $\{\bar{1}\bar{1}\bar{1}\}$. When the complementary forms occur together, if equally developed, the resulting solid (though having two unlike sets of faces, cannot be distinguished geometrically from the first order pyramid $\{111\}$).



In the species chalcopyrite, which belongs to this class, the deviation in angle and in axial ratio from the isometric system is very small, and hence the unit sphenoid cannot by the eye be distinguished from a tetrahedron (compare Fig. 227 with Fig. 182, p. 84). For this species $c = 0.98a$ (instead of 1, as in the isometric system), and the normal sphenoidal angle is $108^\circ 40'$, instead of $109^\circ 28'$, the angle of the tetrahedron. Hence a crystal of chal-

chalcopyrite with both the positive and negative sphenoids equally developed closely resemble as a regular octahedron.

In Fig. 225 the second order pyramids $\epsilon(101)$ and $\epsilon(201)$ and base $\epsilon(001)$ are also present.

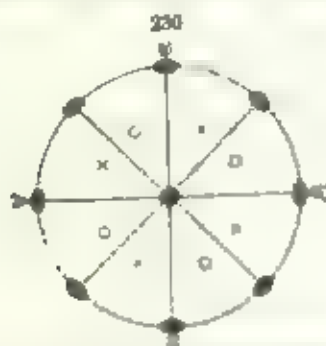
110. Tetragonal Scalenohedron.—The sphenoidal symmetry yields another distinct type of form, that shown in Fig. 226. It is bounded by eight similar scalene triangles, and hence is called a *tetragonal scalenohedron*; the general symbol is $\{hkl\}$. It may be considered as derived from the tetragonal pyramid of the normal class by taking the alternate pairs of faces of the latter form. The faces of the complementary positive and negative forms therefore embrace all the faces of the ditetragonal pyramid. This form appears in combination in chalcopyrite, but is not observed independently. In Fig. 229 the form $\epsilon\{011\}$ is the positive tetragonal scalenohedron.

111. Other Forms.—The other forms of the class, namely, the first and second order prisms the ditetragonal prism and the first and second order pyramids (hkl and hkl), are geometrically like those of the normal class. The lower symmetry in the molecular structure is only revealed by special investigation, as by etching.

6. TRAPEZOHEDRAL CLASS (11) NICKEL SULPHATE TYPE

(*Tetragonal Trapezohedral, Trapezohedral Hemihedron or Tetragonal Holohedral Class*)

112. Vert. Ax.-4; 4 hor. Ax.-2—The trapezohedral class is analogous to the plagioclinal class of the isometric system. It is characterized by the absence of any plane or center of symmetry, the vertical axis, however, is



Symmetry of Trapezohedral Class



Tetragonal Trapezohedron

an axis of tetragonal symmetry and perpendicular to this there are four axes of binary symmetry. The symmetry in the distribution of the faces of the general form (hkl) are shown in the stereographic projection, Fig. 230, and Fig. 231 gives the resulting solid, a *tetragonal trapezohedron*. It may be derived from the ditetragonal pyramid of the normal class by the extension of the alternate faces of that form. There are two complementary forms called right- and left-handed which embrace all the faces of the ditetragonal pyramid

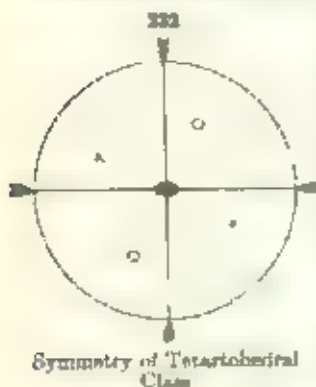
of the normal class. These two forms are enantiomorphous, and the salts belonging to this class show circular polarization of light.

Nickel sulphate and a few other artificial salts belong in this class.

7 TETARTOHEDRAL CLASS (12)

(*Tetragonal Disphenoidal, Sphenoidal Tetartohedral, or Tetragonal Alternating Class*)

113 Symmetry Vert. Ax-2—The seventh and last possible class under this system has no plane or center of symmetry, but the vertical axis is an axis of binary symmetry. The symmetry and the distribution of the faces of the general form (*hkl*) are shown in the stereographic projection (Fig. 232), and the resulting solid is known as a *sphenoid of the third order*. It can be derived from the tetragonal pyramid of the normal class by taking only one quarter of the faces of that form. There are therefore four enantiomeric forms which are respectively distinguished as right (+) and left (−), and these four together embrace all the sixteen faces of the tetragonal pyramid. The other characteristic forms of this class are the prism of the third order (*hkl*), the positive and negative sphenoids of the first order (111), and also those of the second order (101). It is said that an artificial compound, $2C_6H_5Al_2O_3SiO_3$, crystallizes in this class.



MATHEMATICAL RELATIONS OF THE TETRAGONAL SYSTEM

114. Choice of Axes.—It appears from the discussion of the symmetry of the seven classes of this system that with all of them the position of the vertical axis is fixed. In classes 1, 2, however, where there are two sets of vertical planes of symmetry, either set may be made the axial plane and the other the laguna plane. The choice between these two possible positions of the horizontal axis is governed particularly by the habit of the occurring crystals and the relations of the given species to others of similar form. With a species whose crystal characters have been described it is unnecessary to follow the orientation given in the original description.

116. Determination of the Axial Ratio, etc.—The following relations serve to connect the axial ratio, that is, the length of the vertical axis c , when $a = 1$, with the fundamental angles ($001 \wedge 101$) and ($001 \wedge 111$)

$$\tan (001 \wedge 101) = c, \quad \tan (001 \wedge 111) = \frac{1}{2}\sqrt{2} = c$$

For faces in the same rectangular zone the tangent principle applies. The most important cases are:

$$\begin{aligned} \frac{\tan (001 \wedge 101)}{\tan (001 \wedge 101)} &= \frac{h}{l}; \\ \frac{\tan (001 \wedge 0kl)}{\tan (001 \wedge 011)} &= \frac{k}{l}; \\ \frac{\tan (001 \wedge hkl)}{\tan (001 \wedge 111)} &= \frac{h}{1}. \end{aligned}$$

For the prisms

$$\tan (010 \wedge hkl) = \frac{h}{k}, \quad \text{or} \quad \tan (100 \wedge hkl) = \frac{k}{h}$$

116. Other Calculations. — It will be noted that in the stereographic projection Fig. 210 all these spherical triangles are right-angled which are formed by great circles (hemispheres) which meet the primitive semi-circle 100, 010, 100, 010. Again all these forms by great circles drawn between 100 and 110 or 010 and 010 and crossing respectively the semi-circles 100, 001, 100, or 010 or 1, 010. Also, all have formed by great circles drawn between 110 and 110 and crossing the semi-circle 110, 001, 110, or between 110 and 110 and crossing the semi-circle 110, 001, 110.

These spherical triangles may hence be readily used to calculate any angles desired for example, the angles between the pole of one face as hkl as 111 and the pinacoids 100, 010, 001. The terminal angles x and y , Fig. 205 of the ditetragonal pyramid, $2 \wedge 212$ or $2 \wedge 113$, etc., and $212 \wedge 110$ or $113 \wedge 110$ etc. can also be obtained in the same way. The zonal relations give the relations of the poles on the zones 001, 010 and 001, 110 for the given case. For example, the zone-circle 110, 010, 110 meets 110, 001, 110 at the pole 212 and the calculated angle $113 \wedge 212$ is half the angle $113 \wedge 010$. If a large number of similar angles are to be calculated, it is more convenient to use a formula, as that given below.

117. Formulas. It is sometimes convenient to have the normal interfacial angles expressed directly in terms of the axis c and the indices h , k , and l . Thus the distances of the pole of any face $P(hkl)$ from the pinacoids $a, (100) = Pc$, $b(010) = Pb$, $c(001) = Pc$ are given by the following equations:

$$\cos^2 Pa = \frac{h^2 c^2}{h^2 c^2 + k^2 c^2 + l^2}, \quad \cos^2 Pb = \frac{k^2 c^2}{h^2 c^2 + k^2 c^2 + l^2}, \quad \cos^2 Pc = \frac{l^2}{h^2 c^2 + k^2 c^2 + l^2}.$$

These may also be expressed in the form

$$\tan^2 Pa = \frac{k^2 c^2 + l^2}{h^2 c^2}, \quad \tan^2 Pb = \frac{h^2 c^2 + l^2}{k^2 c^2}, \quad \tan^2 Pc = \frac{h^2 c^2 + k^2 c^2}{l^2}.$$

(2) For the distance between the poles of any two faces (hkl), ($h'k'l'$), we have in general

$$\cos PQ = \frac{hpc^2 + k'p'c^2 + l^2}{\sqrt{(h^2 c^2 + k^2 c^2 + l^2)(h'^2 c^2 + k'^2 c^2 + l'^2)}}$$

The above equations take a simpler form for special cases often occurring, for example, for hkl and the angle of the edge z of Fig. 206.

118. Prismatic Angles. — The angles for the commonly occurring ditetragonal prisms are as follows:

	Angle on $a(100)$	Angle on $m(110)$		Angle on $a(100)$	Angle on $m(110)$
410	15° 21'	30° 57½'	530	30° 57½'	14° 21'
310	18 26	26 34	320	33 41½	11 18½
210	28 34	18 26	430	38 52½	8 7½

119. To determine, by plotting, the axial ratio, c/a , of a tetragonal mineral from the stereographic projection of its crystal forms. As an illustrative example I have been assuming that the angles between the faces in the crystal of rutile represented in Fig. 195, mentioned and from these measurements the poles of the faces in an octant have been measured and from these measurements the poles of the faces in an octant located on the stereographic projection, see Fig. 233. In determining the axial ratio of a tetragonal crystal or what is the same thing, the length of two c axes, since the length of the a axes are always taken as equal to 1. It is necessary to assume the position of some of the a axes to take a pyramid which is prominent upon the crystalline pyramidal form. It is customary to take the fundamental or unit pyramid of either the first or of the second order and assume that it is the fundamental or unit pyramid of either the first or of the second order and has as its symbol either 111 or 101. In the example chosen both a second order and a second order pyramid are present and from their axial relations it is evident that if the symbol assigned to the first order form be 111 that of the second order form must be (101). In order to determine the relative length of the c axis in respect to the length of the a axis for rutile, therefore, it is only necessary to plot the intercept of either of these forms upon the axes. In the case of the second order pyramid it is only necessary to construct a right angle triangle on upper left-hand quadrant of Fig. 233 in which the horizontal side shall equal the length of the a axis, 1. The vertical side shall represent the c axis and the hypotenuse shall show the proper angle of slope of the face. The angle between the center of the projection and the pole 101 is measured by the stereographic protractor and a line drawn making that angle with the line representing the

c axis. The hypotenuse of the triangle must then be at right angles to this pole. Its intercept upon the vertical axis of the triangle, when expressed in relation to the distance OP which was assumed as representing c upon the c axis, will therefore give the length of the c axis. In reality this is found to be 1.664.

The same result is obtained when the position of the pyramid of the first order $\{111\}$ is used. In this case we use OP as the radius at right angles to the radius, the OP drawn through the pole $\{111\}$. The triangle to be plotted in this case has the distance OP as the length of its horizontal side. Its hypotenuse must be at right angles to the c representing the pole to $\{111\}$. The intercept on the c axis is the same as in the first case.

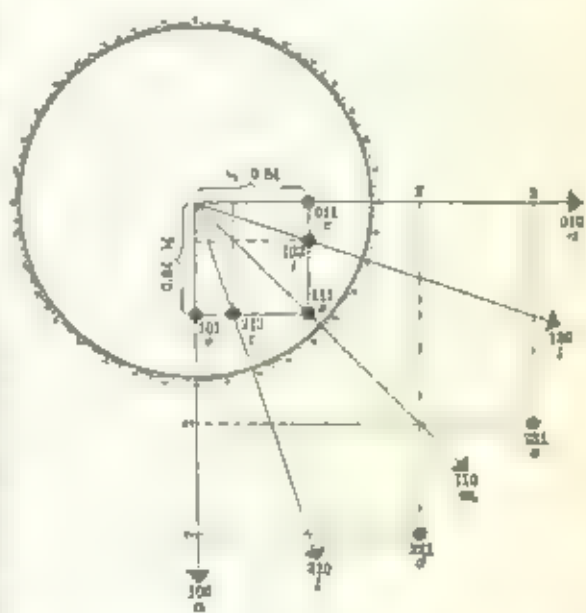
120. To determine, by plotting the indices of any face hkl of a tetragonal form from the position of its pole on the stereographic projection. The solution of this problem is the same as that given in a similar case under the isometric system (see p. 10) except that the intercept of the face on the vertical axis must be referred to the c distance, and length of that axis and not to the length of the a axis. The method is exactly the reverse of the one used in the previous case, and correctly gives

121. To determine, by plotting, the axial ratio, $a : c$, of a tetragonal mineral from the gnomonic projection of its crystal forms. As an illustrative example consider the crystal of rutile (Fig. 129), the axes to the faces of which are shown just as in gnomonic projection in Fig. 235. The crystals of the first and second order pyramids are taken as the main forms with the symbols $\{111\}$ and $\{211\}$. The lines OM and ON represent the two horizontal axes a_1 and a_2 and the distance from the center O to the circumference of the fundamental circle is equal to unity on these axes. The intercepts on OM and ON since c is the pole of $\{101\}$ or the perpendicular drawn from the poles of $\{111\}$ give the unit length of the vertical axis, c . In this case the distance, when expressed in terms of the assumed length of the horizontal axes which in the tetragonal system always equals a , is equal to 0.64.

That the above relation is true is shown from a comparison of Fig. 234. The representation a vertical section through the spherical and gnomonic projections including the horizontal axis, a_1 . The slope of the face $\{011\}$ is plotted with its intercepts on the a_1 and c axes and the position of its pole in both the spherical and gnomonic projections is shown. It is seen through the two similar triangles in the figure that the distance from the center to the pole $\{011\}$ in the gnomonic projection must be the same as the intercept of this face upon the vertical axis c . And as c is a unit length this must represent unity on c .

122. To determine, by plotting, the indices of any face of a tetragonal form from the position of its pole on the gnomonic projection. It is assumed that in this case a mineral is being examined whose axes are a_1, a_2 and c . Under these conditions draw perpendiculars from the pole of a face to the a_1 and a_2 axes representing the two horizontal axes. Then space off on these lines distances equal to the length of the c axis, remembering that c can be expressed in terms of the length of the horizontal axes which in turn is equal to the distance from the center in the projection to the circumference of the fundamental circle. Carry the intercepts of the axes drawn from the pole of the face to the axes a_1 and a_2 in terms of the

235



positive and negative ends of the axes are shown in Fig. 236. The general position of any plane may be expressed in a manner analogous to that applicable in the other systems, viz

$$\frac{1}{h} a_1 \quad \frac{1}{k} a_2 \quad \frac{1}{l} a_3$$

The corresponding indices for a given plane are then h, k, l , these always refer to the axes named in the above scheme. Since it is found convenient to consider the axis a_3 as negative in front and positive behind, the general symbol becomes hkl . Further, as following from the angular relation of the three horizontal axes, it can be readily shown to be always true that the algebraic sum of the indices h, k, l , is equal to zero:

$$h + k + l = 0$$

A. Hexagonal Division

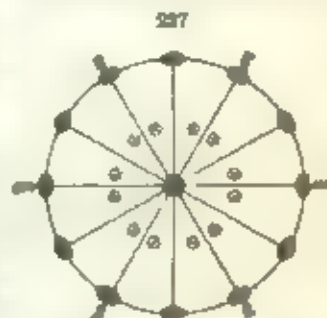
1. NORMAL CLASS (13) BERYL TYPE

(*Dihexagonal Dipyramidal, Holohedral, or Dihexagonal Equatorial Class*)

126. Symmetry. Vert. Ax.-6; 6 hor Ax.-2, 6 vert P., hor P., C. — Crystals belonging to the normal class of the Hexagonal Division have one principal axis of hexagonal, or sixfold symmetry which coincides with the vertical crystallographic axis, also six horizontal axes of binary symmetry; three of these coincide with the horizontal crystallographic axes, the others bisect the angles between them. There is one principal plane of symmetry which is the plane of the horizontal crystallographic axes and six vertical planes of symmetry which meet in the vertical crystallographic axis. Three of these vertical planes include the horizontal crystallographic axes and the other three bisect the angles between the first set.

The symmetry of this class is exhibited in the accompanying stereographic projection, Fig. 237, and by the following crystal figure.

The analogy between this class and the normal class of the tetragonal system is obvious at once and will be better appreciated as greater familiarity is gained with the individual forms and their combinations.



Symmetry of Normal Class

127. Forms. The possible forms in this class are as follows:

Miller-Bravais

- | | |
|--------------------------------|-------------------------------|
| 1. Base | (0001) |
| 2. Prism of the first order | (1010) |
| 3. Prism of the second order | (1120) |
| 4. Dihexagonal prism | (hki0) as, (2130) |
| 5. Pyramid of the first order | (hkl) as, (1011), (2021) etc. |
| 6. Pyramid of the second order | (hkh2l) as, (1122) |
| 7. Dihexagonal pyramid | (hkl) as, (2131) |

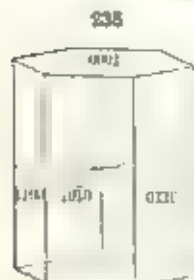
In the above $h > k$, and $h + k = 1$.

128. Base. — The *base*, or *basal pinacoid*, includes the two faces, 0001 and $\bar{000}\bar{1}$, parallel to the plane of the horizontal axes. It is uniformly designated by the letter *c*, see Fig. 238 et seq.

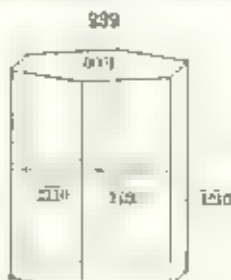
129. Prism of the First Order — There are three types of prisms, or forms in which the faces are parallel to the vertical axis.

The *prism of the first order*, Fig. 238, includes six faces, each one of which is parallel to the vertical axis and meets two adjacent horizontal axes at equal distances, while it is parallel to the third horizontal axis. It has hence the general symbol $\{10\bar{0}\}$ and is uniformly designated by the letter *m*, the indices of its six faces taken in order see Figs. 238 and 247. 248 are:

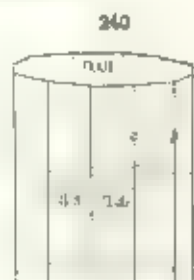
$$10\bar{1}0, 01\bar{1}0, \bar{1}100, 1010, 0\bar{1}10, 1\bar{1}00.$$



First Order Prism



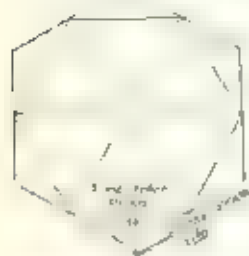
Second Order Prism



Dihexagonal Prism

130. Prism of the Second Order. The *prism of the second order*, Fig. 239, has six faces, each one of which is parallel to the vertical axis and meets the two horizontal axes at unequal axes at the unit distance, the intermediate axis at one half this distance, or which is the same thing, it meets the first named axis at the unit distance, the others at double this distance*. The general symbol is $\{11\bar{2}0\}$ and it is uniformly designated by the letter *n*, the indices of the six faces (see Figs. 240 and 247, 248) in order are:

241



$$11\bar{2}0, 1\bar{2}10, \bar{2}110, 1120, 1\bar{2}10, 21\bar{1}0$$

The first and second order prisms are not to be distinguished geometrically from each other since each is a regular hexagonal prism with normal interfacial angles of 60° . They are related to each other in the same way as the two prisms m and n in the tetragonal system.

The relation in position between the first order prism and pyramid on the one hand and the second order prism and pyramid on the other will be understood better from Fig. 241, representing a cross section of the two prisms parallel to the base *c*.

131. Dihexagonal Prism The *dihexagonal prism*, Fig. 240, is a twelve-sided prism composed of twelve faces, each one of which is parallel to the

* Since $1/2 = 1/2$, $1/2 = 1/2$, etc. is equivalent to $1/2 = 1/2$, $1/2 = 1/2$, etc.

vertical axis, and also meets two adjacent horizontal axes at unequal distances, the ratio of which always lies between 1 : 1, and 1 : 2. This prism has two unlike edges, lettered x and y , as shown in Fig. 240. The general symbol is hkl , and the indices of the faces of a given form, as $(2\bar{1}30)$, are:

$$\begin{array}{cccccc} 2\bar{1}40 & 1230 & 1\bar{2}20 & 2310 & \bar{3}210 & \bar{1}120 \\ 2\bar{1}30 & 1\bar{2}30 & 1\bar{3}20 & 2\bar{3}10 & \bar{3}2\bar{1}0 & \bar{1}\bar{1}20 \end{array}$$

132. Pyramids of the First Order. Corresponding to the three types of prisms just mentioned, there are three types of pyramids.

A *pyramid of the first order* (Fig. 242) is a double six-sided pyramid (or dipyrmaid) bounded by twelve similar triangular faces—six above and six below—which have the same position relative to the horizontal axes as the faces of the first order prism, where they also intersect the vertical axis above and below. The general symbol is hence $h0h$. The faces of a given form, as $(10\bar{1}1)$, are:

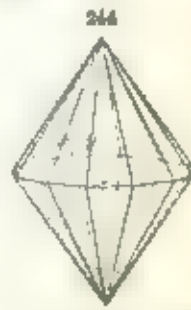
$$\begin{array}{ccccccc} \text{Above} & 10\bar{1}1 & 01\bar{1}1 & 1\bar{1}01 & \bar{1}011 & 0\bar{1}11 & \bar{1}\bar{1}01 \\ \text{Below} & 101\bar{1} & 011\bar{1} & 110\bar{1} & \bar{1}01\bar{1} & 0\bar{1}1\bar{1} & \bar{1}\bar{1}0\bar{1} \end{array}$$



First Order Pyramid



Second Order Pyramid



Dimerismus Pyramid

On a given species there may be a number of pyramids of the first order, differing in the ratio of the intercepts on the horizontal to the vertical axis, and thus forming a zone between the base (0001) and the faces of the unit prism (1010) . Their symbols passing from the base (0001) to the unit prism (1010) , would be, for example, 1014 , 1012 , $20\bar{1}3$, $10\bar{1}1$, 3032 , 2021 , etc. In Fig. 244 the faces p and a are first order pyramids and they have the symbols respectively $(10\bar{1}1)$ and 2021 , where $c = 0.4989$. As shown in these cases the faces of the first order pyramids replace the edges of the first order prism. On the other hand, they replace the solid angles of the second order prism, as 1120 .

133. Pyramids of the Second Order. The *pyramid of the second order* (Fig. 243) is a double six-sided pyramid including the twelve similar faces which have the same position relative to the horizontal axes as the faces of the second order prism, and which also intersect the vertical axis. They have the general symbol $(h\ h\ 2h\ \bar{4})$. The indices of the faces of the form (1122) are:

$$\begin{array}{cccccc} \text{Above} & 11\bar{2}2 & \bar{1}212 & \bar{2}112 & \bar{1}\bar{1}22 & 1\bar{2}12 & 2\bar{1}\bar{1}2 \\ \text{Below} & 112\bar{2} & \bar{1}2\bar{1}2 & \bar{2}1\bar{1}2 & 1\bar{1}2\bar{2} & 1\bar{2}\bar{1}2 & 2\bar{1}\bar{1}2 \end{array}$$

This form (11 $\bar{2}$ 2) is to be considered as the unit second order pyramid, rather than the form (11 $\bar{1}$ 1). Thus is seen when the parameters are noted, viz., $2a_1$, $2a_2$, $1a_3$, $1a_4$. Its indices are also to be obtained by adding those of the faces of the first order unit pyramid between which it lies, as (1011) + (0111) = (11 $\bar{2}$ 2).

The faces of the second order pyramid replace the edges between the faces of the second order prism and the base. Further, they replace the solid angles of the first order prism, $m, 10\bar{1}0$. There may be on a single crystal a number of second order pyramids forming a zone between the base $c(0001)$ and the faces of the second order prism $a(11\bar{2}0)$ as, naming them in order 11 $\bar{2}$ 4, 11 $\bar{2}$ 2, 2 $\bar{2}$ 43, 11 $\bar{2}$ 1, etc. In Fig. 245, s is the second order pyramid (11 $\bar{2}$ 1).

134. Dihexagonal Pyramid. -- The *dihexagonal pyramid*, Fig. 244 is a double twelve-sided pyramid having the twenty-four similar faces embraced under the general symbol $h\{2\bar{1}3\}$. It is bounded by twenty-four similar faces, each meeting the vertical axis, and also meeting two adjacent horizontal axes at unequal distances, the ratio of which always lies between 1/3 and 1/2. Thus the form (21 $\bar{3}$ 1) includes the following twelve faces in the upper half of the crystal

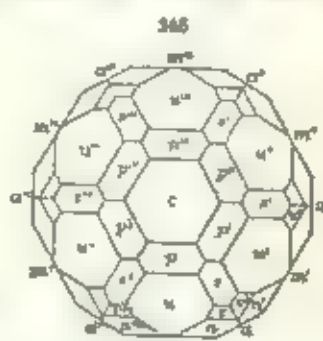
$$\begin{array}{cccccc} 21\bar{3}1, & 12\bar{3}1, & 1\bar{3}31, & 2\bar{3}11, & 3211, & 3121, \\ 2\bar{1}31, & 1\bar{2}31, & 13\bar{2}1, & 2411, & 3\bar{2}11, & 31\bar{2}1 \end{array}$$

And similarly below with l (here 1) negative, 21 $\bar{3}\bar{1}$ etc. The dihexagonal pyramid is often called a *beryl* because a common form with the species beryl. The dihexagonal pyramid $m\{2\bar{1}3\}$, is shown on Figs. 242-243.

135. Combinations. Fig. 245 of beryl shows a combination of the base $c(0001)$, and prism $m(10\bar{1}0)$ with the first order pyramids $p(10\bar{1}1)$ and

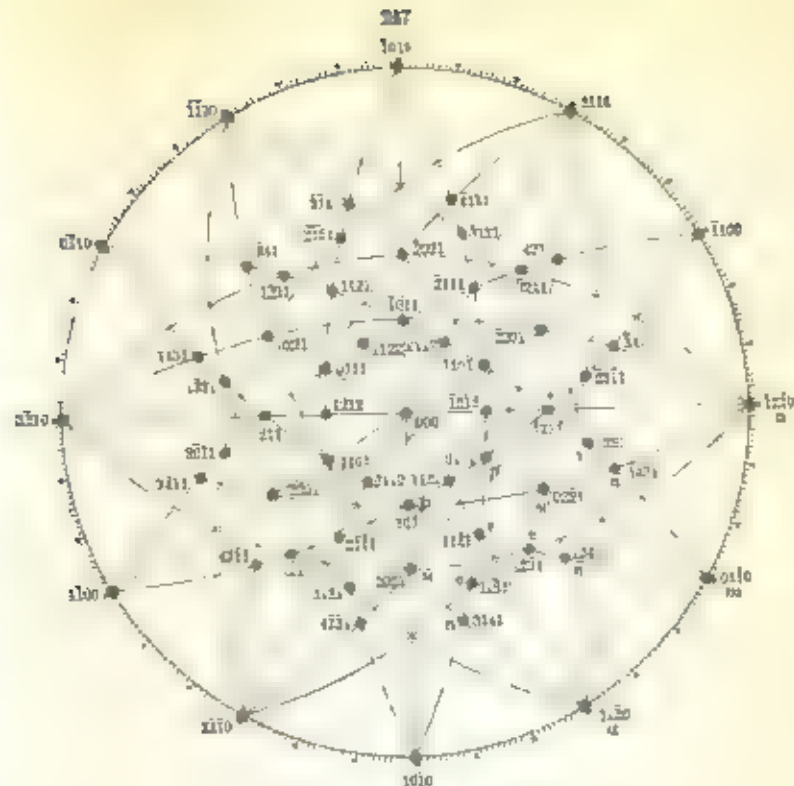


Beryl

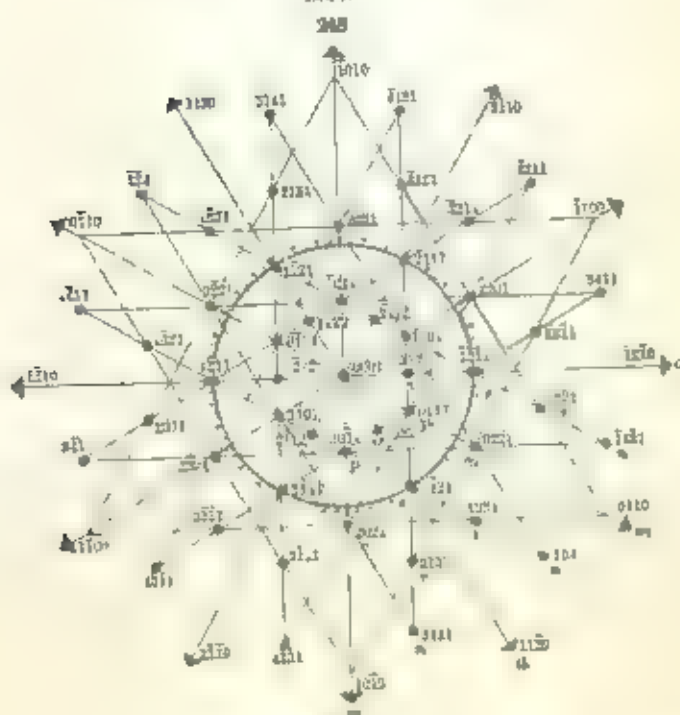


Beryl

$a(20\bar{2}1)$, the second order pyramid $s(11\bar{2}1)$ and the dihexagonal pyramid $m\{2\bar{1}3\}$. The basal projection of a similar crystal shown in Fig. 246 is very instructive as explaining the symmetry of the normal hexagonal class. This is also true of the stereographic and gnomonic projections in Figs. 247 and 248 of a like crystal with the added form $a(11\bar{2}2)$.



Beryl

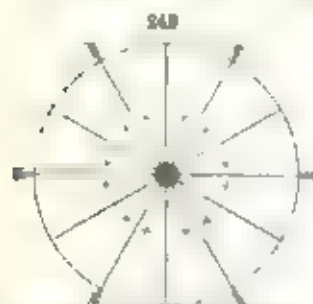


Beryl

2. HEMIMORPHIC CLASS (14) ZINCITE TYPE

(Dihexagonal Pyramidal Holohedral Hemimorphic, or Dihexagonal Polar Class)

136. Symmetry Vert. A_2-6 ; 6 vert. P. — This class differs from the normal class only in having no horizontal plane of principal symmetry and no horizontal axes of binary symmetry. It has,



Symmetry of Hemimorphic Class

is found in zincite (Fig. 44, p. 23). Letyrite, greenockite and wurtzite are also classed here.

however, the same six vertical planes of symmetry meeting at angles of 60° in the vertical crystallographic axis with a six-axis of hexagonal symmetry. There is no center of symmetry. The symmetry is exhibited in the stereographic projection, Fig. 249.

137. Forms. The forms belonging to this class are the two based planes or prisms $\{0001\}$ and $\{00\bar{1}\}$, here perfect forms, the positive (upward) and negative (lower) pyramids of each of the three types, also the three prisms, which last do not differ geometrically from the prisms of the normal class. An example of this case

3. TRIPYRAMIDAL CLASS (15) APATITE TYPE

(Hexagonal Dipyramidal, Pyramidal Hemihedral or Hexagonal Equatorial Class)

138. Typical Forms and Symmetry Vert. A_2-6 , hor P; C. — This class is important because it will also contain all species of the Apatite Group, apatite, pyramorphite, monite, canadite. The typical form is the hexagonal prism $\{hk\bar{1}0\}$ and the hexagonal pyramid $\{hkl\}$, each designated as of the third order. These forms which are shown in Figs. 251 and 252 may be considered as derived from the corresponding dihexagonal forms of the normal class by the omission of one half of the faces of the latter. They and the other forms of the class have only one plane of symmetry, the plane of the horizontal axes, and also one axis of hexagonal symmetry, the vertical axis.

The symmetry is exhibited in the stereographic projection (Fig. 250). It is seen here, as in the figures of crystals given, that like the tripysmidal class under the hexagonal system, the faces of the general form $\{hk\bar{1}l\}$ present are half of the possible planes belonging to each sector, and further that those above and below fall in the same vertical zone.



Symmetry of Tripysmidal Class

139. Prism and Pyramid of the Third Order The prism of the third order (Fig. 251) has six like faces embraced under the general symbol $\{hk\bar{1}0\}$,

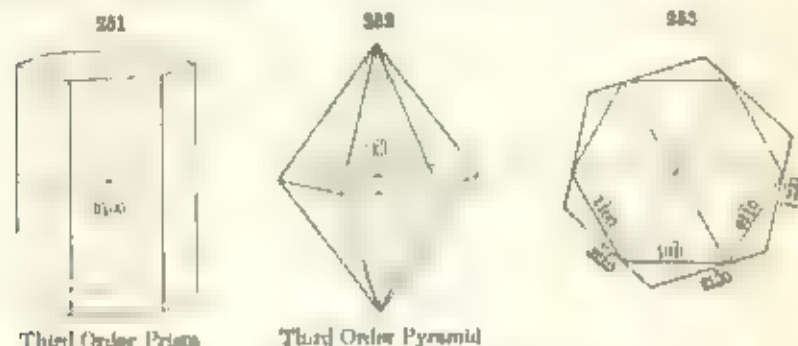
and the form is a regular hexagonal prism with angles of 60° not to be distinguished geometrically if alone from the other hexagonal prisms, of Figs. 238, 239, p. 112. The six faces of the right-handed form, 2130, have the indices

$$21\bar{3}0, \bar{1}\bar{3}20, 3210, 2130, 1\bar{3}20, 3\bar{2}10$$

The faces of the complementary left-handed form have the indices

$$12\bar{3}0, 2310, 3120, \bar{1}230, 2310, 31\bar{2}0.$$

As already stated these two forms together embrace all the faces of the dihexagonal prism (Fig. 240).



The pyramid is also a regular double hexagonal pyramid of the third order, and in its relations to the other hexagonal pyramids of the class (Figs. 242, 243) it is analogous to the square pyramid of the third order (see Art. 104). The faces of the right-handed form, 2131, are

$$\begin{array}{l} \text{Above } 21\bar{3}1, \bar{1}\bar{3}21, 3211, 2131, 1\bar{3}21, 3\bar{2}11 \\ \text{Below } 21\bar{3}\bar{1}, \bar{1}\bar{3}\bar{2}\bar{1}, 32\bar{1}\bar{1}, 21\bar{3}\bar{1}, 1\bar{3}\bar{2}\bar{1}, 3\bar{2}\bar{1}\bar{1}. \end{array}$$

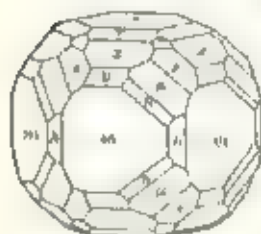
There is also a complementary left-handed form which with this embraces all the faces of the dihexagonal pyramid. The cross section of Fig. 253 shows in outline the position of the first order prism, and also that of the right-handed prism of the third order.

The prism and pyramid just described do not often appear on crystals as predominate forms though this is sometimes the case, but commonly these faces are present involving other fragmentary forms.

140. Other Forms.—The remaining forms of the class are geometrically like those of the normal class, viz. the base 0001 , the first order prism $10\bar{1}0$, the second order prism 1120 , the first order pyramids $h0h1$ and the second order pyramids $hkh2h1$. That their molecular structure, however, corresponds to the symmetry of this class is readily proved, for example, by etching. In this way it was shown that pyromorphite and mimetite belonged in the same group with apatite (Basthauer) though crystals with the typical forms had not been observed. This class is given its name of *Tripyramidal* because its forms include three distinct types of pyramids.

141. A typical crystal of apatite is given in Fig. 254. It shows the third order prism $h(21\bar{3}0)$, and the third order pyramids $\mu(21\bar{5}1)$, $\nu(31\bar{4}1)$, also the first order pyramids $r(10\bar{1}2)$, $z(10\bar{1}1)$, $y(20\bar{2}1)$, the second order pyramids $\epsilon(11\bar{2}2)$, $s(11\bar{2}1)$, finally the prism, $m(10\bar{1}0)$, and the base $c(0001)$.

254



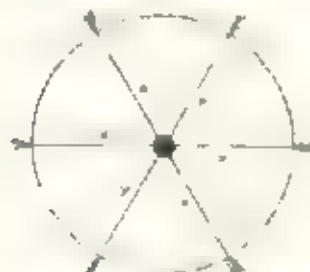
Apatite

4 PYRAMIDAL HEMIMORPHIC CLASS (16) NEPHELITE TYPE

Hexagonal Pyramidal, Pyramidal Hemihedral, Hemimorphic, or Hexagonal Polar Class

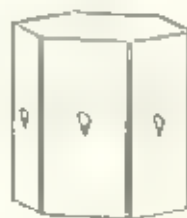
142. **Symmetry.** **Vert. Ax. 6.** — A fourth class under the hexagonal division, the *pyramidal hemimorphic class*, is like that just described, except that the forms are hemimorphic. The single horizontal plane of symmetry is absent, but the vertical axis is still an axis of hexagonal symmetry. This symmetry is shown in the stereographic projection of Fig. 255. The typical

255



Symmetry of Pyramidal Hemimorphic Class

256



Nephelite

form would be like the upper half of Fig. 252 of the pyramidal, the third order. This species nephelite is shown by the character of the c cleaving figures (Fig. 256, Grett) after Beudanticite) is being here.

5 TRAPICZOHEDRAL CLASS (17), β QUARTZ TYPE

Hexagonal Trapezohedral, Trapezohedral Hemihedral, or Hexagonal Holohedral Class

143. **Symmetry.** **Vert. Ax. 6, 6 hor. Ax. 2.** The *trapezohedral class* has no plane of symmetry, but the vertical axis is an axis of hexagonal symmetry, and there are, further, six horizontal axes of binary symmetry. There is no center of symmetry. The symmetry and the distribution of the faces of the typical form *okta* is shown in the stereographic projection (Fig. 257). The typical forms may be derived from the ditetragonal pyramid by the addition of the alternate faces of the latter. There are two possible types known as the right and left hexagonal trapezohedrons (see Fig. 258) which are enantiomorphous, and the few crystallized salts falling in this class show

circular polarization. A modification of quartz known as β -quartz is also described as belonging here. The indices of the right form (2131), are as follows.

Above	2131,	1321,	3211,	131,	1321,	3211
Below	1231,	2311,	3121,	1231,	2311,	3121



Symmetry of Trapezohedral Class

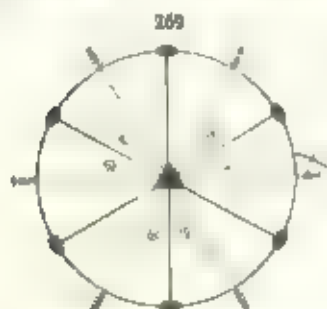


Hexagonal Trapezohedron

6 TRIGONAL CLASS IS BINIFOLIOLE TYPE*

(*Intrigonal Dipyramidal, Trigonal Hemihedral, Trigonaltype, or Ditrigonal Equatorial Class*)

144. Typical Forms and Symmetry. Vert Ax-3; 3 hor. Ax-2; 3 vert. P, hor P. These classes have as their vertical axis of rigidity, symmetry, three horizontal axes of binary symmetry which are diagonal to the crystallographic axes. There are four planes of symmetry, one horizontal, and three



Symmetry of Trigonal Class



Bentonite Palache

vertical diagonal planes intersecting at angles of 60° in the vertical axis. The symmetry and the distribution of the faces of the positive trigonal pyramid are shown in Fig. 259. The characteristic forms are as follows: Trigonal prism consisting of three faces comprising one-half the faces of the

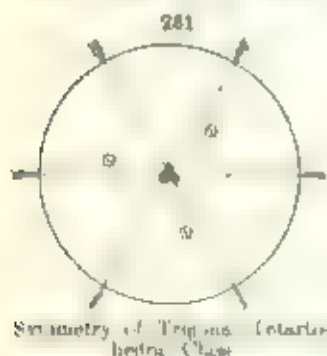
* Symmetry Classes 5 and 19 were formerly grouped under the rhombohedral Division because of their vertical axes of rigidity and symmetry. They were known to be structurally similar to the hexagonal classes and are more properly placed here.

hexagonal prism of the first order. They are of two types called positive (1010) and negative (0110). *Trigonal pyramid* is a double three-faced pyramid, consisting of six faces corresponding to one half the faces of the hexagonal pyramid of the first order. The faces of the upper and lower halves fall in vertical zones with each other. There are two types, called positive (1011) and negative (0111). *Intigonal prism* consists of six vertical faces arranged in three sets at sets of two faces and having therefore the characteristic of differing character. It may be derived from the hexagonal prism by taking alternate pairs of faces. *Intigonal pyramid* consists of twelve faces, six above and six below. It like the prism may be derived from the hexagonal form by taking alternate pairs of faces of the latter. The faces of the upper and lower halves fall in vertical zones. The only representative of this class known is the rare mineral benitoite, a crystal of which is represented in Fig. 200. This crystal shows the trigonal prisms $m(1010)$ and $p(0110)$, the hexagonal prisms of the second order $a(1120)$, the trigonal pyramids $p(1011)$ and $r(0111)$, $r(0112)$ and the hexagonal pyramids of the second order $e(2041)$.

7. TRIGONAL TRICARTOONEDRAL, OR POSITIVE RHOHEDRAL PHOSPHATE TYPE.

Trigonal Dipyramidal or Trigonal Equatorial Class

145. Vert. Ax-3, hor P



This class has one plane of symmetry, that of the horizontal axes and the axis of trigonal symmetry. The vertical axis has no other symmetry. Each tricartooned form in the three types of trigonal prisms and the three corresponding types of trigonal pyramids, of Fig. 261, of this class has no known representation among minerals.

B. Rhombohedral Division

Five classes are included in the Rhombohedral Division of the Hexagonal System, of which the rhombohedral class of the Calcite type is by far the most important.

1. RHOMBOHEDRAL CLASS (20) CALCITE TYPE

(Intigonal Scalenohedral, Hexagonal Scalenohedral, Rhombohedral Hemihedral or Hexagonal Symmetrical Class)

146. Typical Forms and Symmetry Vert. Ax-3, 3 hor xl Ax-2, 3 vert. diag P, C. The typical forms of the rhombohedral class are the rhombohedron (Fig. 263) and the scalenohedron, (Fig. 274). These forms with the projections, Figs. 262 and 288, illustrate the symmetry character of the class. There are three planes of symmetry only, these are diagonal to the horizontal crystallographic axes and intersect at angles of 60° in the vertical crystallographic axis. This axis is with these forms an axis of trigonal

symmetry, there are, further, three horizontal axes parallel to the crystallographic axes of 4 axis symmetry of Fig. 263 and Fig. 264 at top.

By comparing Fig. 288 with Fig. 247 p. 115 it will be seen that all the faces of this crystal are present. This group is hence analogous to the tetrahedral class of the isometric system, and, the symmetrical class of the tetragonal system.

147. Rhombohedron. Geometrically described the *rhombohedron* is a six-faced polyhedron like faces, such a rhomb, forming a crystal habit about a crystal axis. The terminal edges, three above and three in front, are parallel to each other. The vertical axis joins the two rhombohedral angles, and the horizontal axes join the outer points of the opposite sides, as shown in Fig. 263.

The general symbol of the rhombohedron is $h\bar{h}k$, and the axes of the faces of the unit form $(10\bar{1}1)$ have the indices:

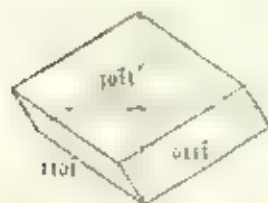
Above $10\bar{1}1$, 101 , $0\bar{1}1$, below, $01\bar{1}$,
 011 , $1\bar{0}1$.

The geometrical shape of the rhombohedron varies widely as the angles change, and causes frequently the relative values of the vertical axis c expressed in terms of the horizontal axes $a = 1$, to vary, the rhombohedron becoming more and more obtuse or flattened, and as it increases they become more and more acute. A cube placed with an octahedral axis vertical is obviously the limiting case between the obtuse and acute forms when the vertical angle is 90° . In Fig. 263 of course the nearest rhombohedral angle is $74^\circ 5'$, $a : c = 0.981$ while for Fig. 265 of last date this angle is 61° and $a : c = 1.365$. Further, Figs. 265-270 show other rhombohedrons of various forms, namely $40\bar{1}12$, $50\bar{1}14$, $70\bar{1}16$, $90\bar{1}18$, and $110\bar{1}10$. Here the vertical axes are in the ratio $\frac{1}{2}, \frac{3}{4}, 1, \frac{4}{3}, \frac{5}{2}$ to that of the fundamental cleavage rhombohedron of Fig. 263 whose angle determines the value of c .

263

Symmetry of Rhombohedron
Cubic

263

Positive Rhombohedron
Cubic

264



Negative Rhombohedron

265

Positive Rhombohedron
Hexagonal

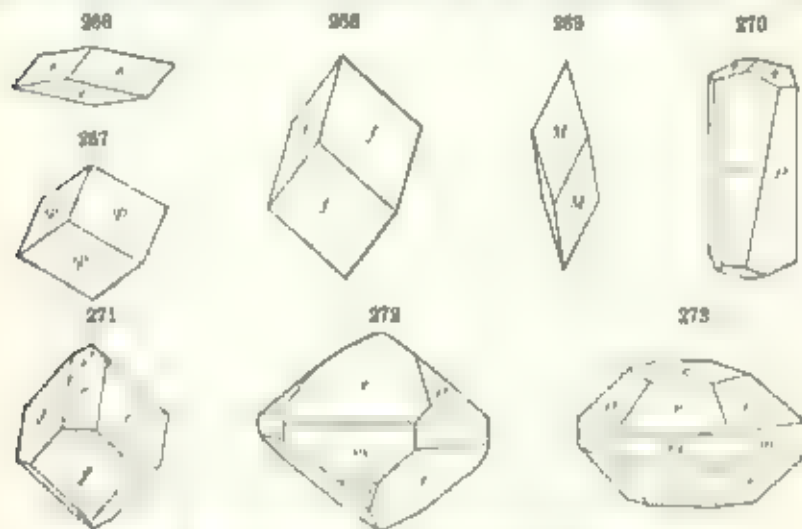
148. Positive and Negative Rhombohedrons. - To every positive rhombohedron there may be an inverse and complementary form, identical geometri-

cally but bounded by faces falling in the alternate octants. Thus the negative form of the unit rhombohedron (0111) shown in Fig. 264 has the faces:

Above, $01\bar{1}1$, 1011 , $1\bar{1}01$ below 1101 , $0\bar{1}11$, $10\bar{1}1$

The position of these in the projections Figs. 268-269 should be carefully studied. The figures closely resemble Figs. 264-265, 266 are positive, and Figs. 264-266, 267-268 negative rhombohedrons, Fig. 270 shows both forms.

It will be seen that the two complementary positive and negative rhombohedrons if given axes length together produce all the side faces of the double six-sided hexagonal pyramid of the first order. When these two rhombohedrons are equally developed the form is geometrically identical with this pyramid. This is illustrated by Fig. 273 of *glaucite* $\pm 10\bar{1}1$, ± 0111 , and by Figs. 303, 304, p. 130, of *quartz* $\pm 10\bar{1}1$, ± 0111 . In each



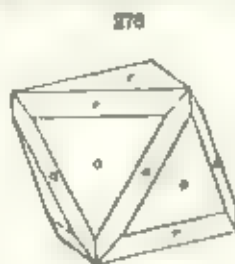
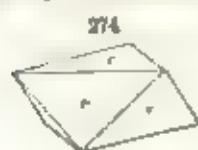
Figs. 266-271, calcite. Figs. 272-273, *glaucite*.

case the form, which is geometrically a double hexagon, extended (in Fig. 273 with *calcite*) is in fact a combination of the two unit rhombohedrons, positive and negative. Comparably different results when the two forms may be observed, as in Figs. 272 and 273, when the form taken as the positive rhombohedron predominates. But even this distinction cannot be established, the two rhombohedrons can always be distinguished by etching, or, in some cases of *quartz*, by pyroelectric phenomena.

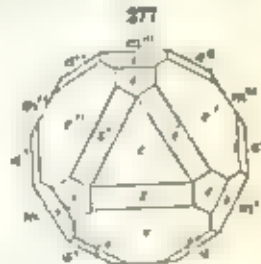
149. Of the two series, or z-pairs, of rhombohedrons the faces of the positive rhombohedrons replace the edge between the base (0001) and the first order prism $\{110\}$. Also the faces of the negative rhombohedrons replace the alternate edges of the same forms, that is, the edges between (0001) and $\{01\bar{1}0\}$, compare Figs. 272-273, etc. Fig. 274 shows the rhombohedron in combination with the base. Fig. 275 the same with the prism at $\{110\}$.

* *Quartz* serves as a convenient illustration of this case, notwithstanding the fact that it belongs to the trapezohedra class of this division.

When the angle between the two forms happens to approximate to $70^{\circ} 42'$ the crystal simulates the aspect of a regular octahedron. This is illustrated by Fig. 276, here $ca = 60^{\circ} 42'$, also $ao = 71^{\circ} 22'$, and the crystal resembles closely an octahedron with truncated edges (cf. Fig. 117 p. 74).



Figs. 274, 275, Hematite



Barite

150. There is a very simple relation between the positive and negative rhombohedrons which it is important to remember. The mn of one series which truncates the terminal faces of a given form of the other w. have one half as intercept on the vertical crystallographic axis as the latter. This ratio is expressed in the values of the indices of the two forms. Thus 0112 truncates the terminal edges of the positive unit rhombohedron (1011); 1014 truncates the terminal edges of 0112; 1115 of 2021. Again 1011 truncates the edges of 0221, 3011 of 0221, etc. Thus it is truncated by Fig. 271 with the forms 1011 and 1021. Also in Fig. 277, a bismuth pyramid (old 4) truncates the edges of a 0112 (old 2) of old 1, and 1011 of a 0211.

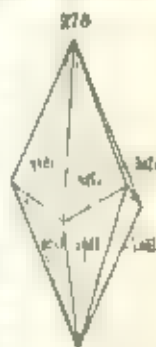
151. **Scalohedron.** The scalohedron shown in Fig. 278, is the general form for this class corresponding to the symbol hkl . It is a solid, bounded by twelve faces, each a rhombic triangle. It has roughly the shape of a dodecahedron, but there are two sets of terminal edges, the more dense than the other, and the lateral edges form a zig-zag edge around the form like that of the rhombohedron. It may be considered as derived from the rhombohedron pyramid by taking the alternating pairs of faces of that form. It should be noted that the faces in the lower half of the form do not fall in vertical lines with those of the upper half. Like the rhombohedrons, the scalohedrons may be either positive or negative. The positive forms correspond in position to the positive rhombohedrons and conversely.

The positive scalohedron (2131), Fig. 278 has the following indices for the several faces:

Above	2131, 2311, 3211, 1231, 1321, 3121
Below	1231, 1321, 3121, 3131, 2311, 3211

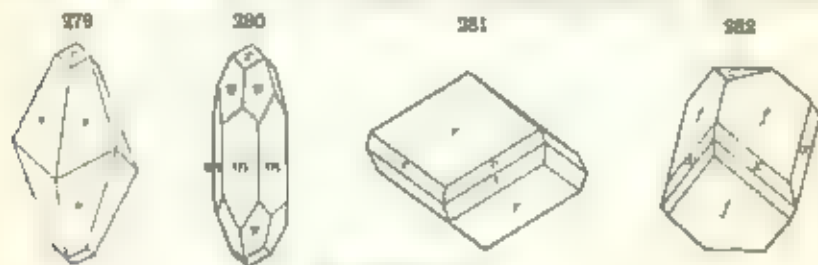
For the complementary negative scalohedron (1231) the indices of the faces are:

Above	1231, 1321, 3121, 2131, 2311, 3211
Below	2311, 3211, 1231, 1321, 3121, 2131

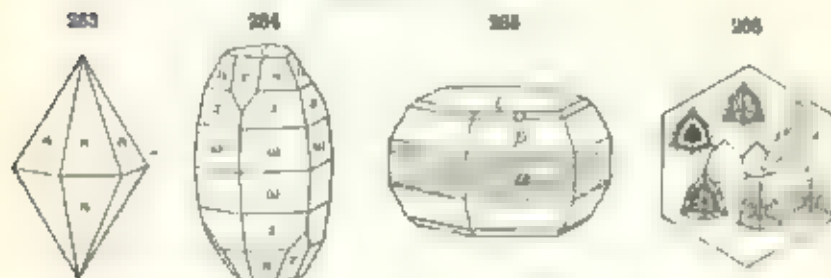


Scalohedron

162. Relation of Scaenohedrons to Rhombohedrons. It was noted above that the scaenohedron in general has a series of aging lateral edges like the rhombohedron. It is important, further, that for every rhombohedron there will be a series of corresponding scaenohedrons having the same lateral edges. This is shown in Fig. 281 where the scaenohedron ± 3 belongs to the lateral edges of the fundamental rhombohedron ± 101 . The same would be true of the scaenohedron ± 21 , etc. Further in Fig. 282, the negative scaenohedron ± 1541 has the lateral edges of the negative rhombohedron ± 022 . The relation of



Figs. 279-283, Calcite

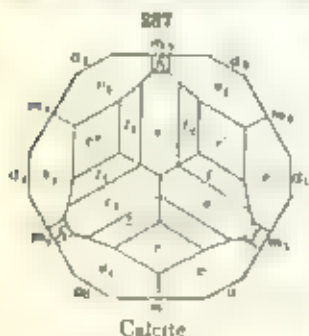


Figs. 284, 285, Corundum

Figs. 285, 286, Hemimorphite*

the indices which must exist in these cases may be shown to be, for example, for the rhombohedron ± 101 , $A = k + l$ (also for ± 022 , $k = 2l - k$, etc.). See also the preceding, Figs. 280, 281. Further, the position of the scaenohedron may be defined with reference to its parent rhombohedron. For example in Fig. 281 the scaenohedron ± 3 has been

turned the vertex away of the parent rhombohedron ± 101 . Again in Fig. 282 ± 1541 has twice the vertical axis of ± 022 .



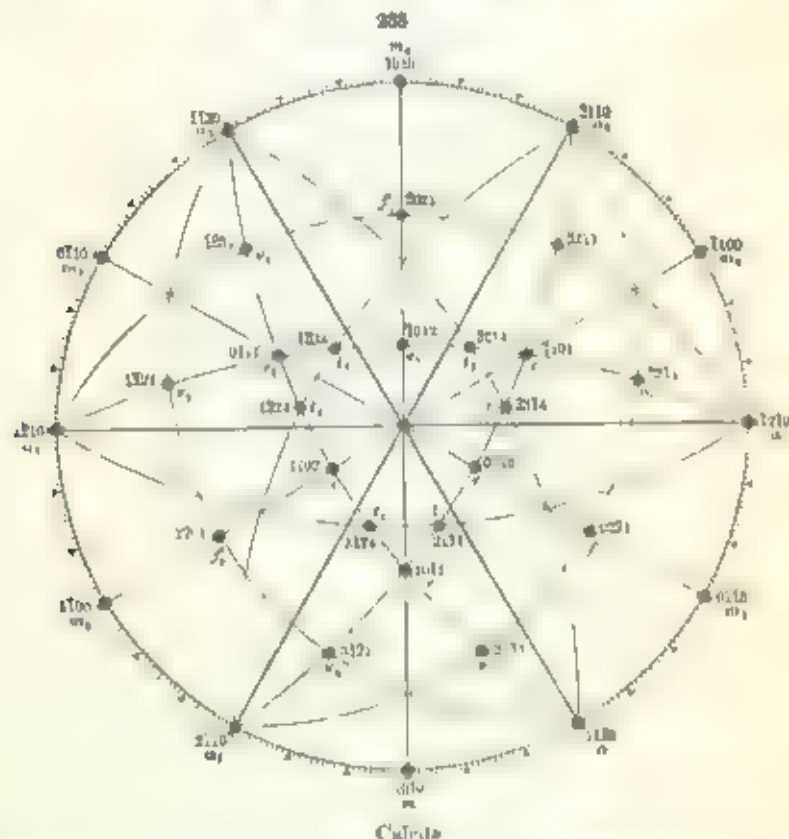
Calcite

163. Other Forms. The remaining forms of this case which might be contrasted with the normal cases of the rhombohedra, however, are geometrically like those of the corresponding cases of the hexagonal, a, a, a, c , viz. the base ± 100 , the prisms ± 1010 and ± 1120 (also ± 1011 and second order pyramids, ± 1121). Several of these forms are shown in the accompanying figures. For further illustrations reference may be made to typical rhombohedral species, as calcite, hemimorphite, etc.

With respect to the second order pyramid it is interesting to note that if

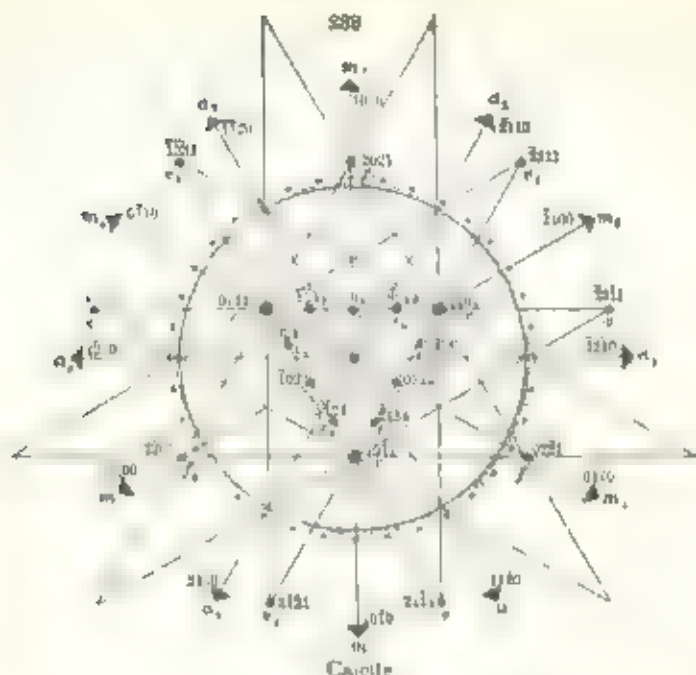
* Hemimorphite belongs properly to the next (hemimorphic) group, but this fact does not destroy the value of the illustration.

it occurs alone (as in Fig. 283 $n = 22\bar{4}3$) it is impossible to say, on geometrical grounds, whether it has the trigonal symmetry of the rhombohedral type or the hexagonal symmetry of the hexagonal type. In the latter case, the form might be made a first order pyramid by exchanging the axial and tangential planes of symmetry. The true symmetry, however, is often indicated, as with corundum, by the occurrence in other crystals of rhombohedral faces, as $r(10\bar{1}1)$, in Fig. 284 (here $z = 22\bar{4}1$, $\omega = 14\bar{1}42\bar{5}3$). Even if



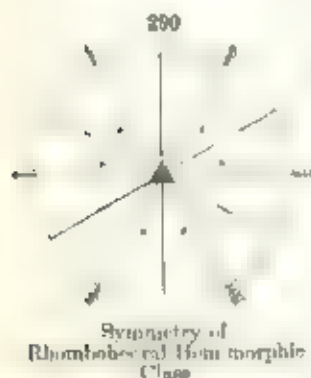
rhombohedral faces are absent (Fig. 295), the sketch-figures (Fig. 286) will often serve to reveal the true trigonal molecular symmetry, here $\sigma = 3121$, $p = 1122$.

154. A basal projection of a somewhat complex crystal of calcite is given in Fig. 287 and stereographic and gnomonic projections of the same forms in Figs. 288 and 289, both show well the symmetry. A the distribution of the faces. Here the forms are prisms, a $11\bar{1}0$, $r(10\bar{1}1)$, rhombohedrons, positive $r(10\bar{1}1)$, negative, $r(01\bar{1}2)$, $f(02\bar{2}1)$, scalenohedrons, positive, $\sigma(21\bar{3}1)$, $\sigma(21\bar{3}4)$.



3 RHOMBOHEDRAL HEMIMORPHIC CLASS 21) TOURMALINE TYPE

(Untrigonal Pyramidal, Trigonal Hemihedral Hemimorphic, or Untrigonal Polar Class)



Symmetry of
Rhombohedral Hemimorphic
Class

155. Symmetry. Vert Ax-3, 3 vert diag. P A number of uniaxial rhombohedric species, as tourmaline, pyrogyrite, pyrochlore, belong to a hemimorphic class under this division. For them the symmetry in the grouping of the faces differs at the two extremities of the vertical axis. The forms have but one three diagonal planes of symmetry meeting at angles of 60° in the vertical axis, which is an axis of trigonal symmetry. There are, however, no horizontal axes of symmetry, as in the rhombohedral class, and there is no center of symmetry, cf. Fig. 200.

156. Typical Forms. In this class the basal planes or poles $\{0001\}$ and $\{000\bar{1}\}$ are distinct forms. The other characteristic forms are the two trigonal prisms $m\{110\}$ and $m\{11\bar{1}\}$ of the first order series, also the four trigonal first order pyramids, corresponding respectively to the three upper or three lower

faces of a positive rhombohedron and the three upper or three lower faces of the negative rhombohedron, also the hexagonal or second-order hexagonal pyramid, finally, the four trigonal pyramids, corresponding to the

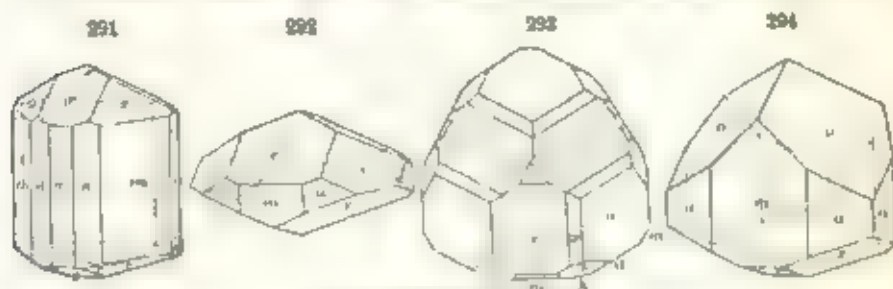


Fig. 291-294, Tourmaline

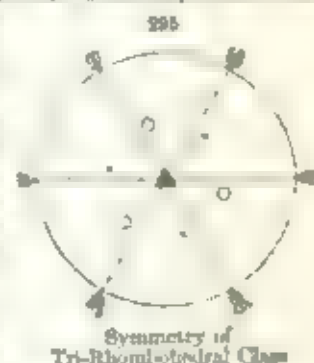
upper or lower faces respectively of the positive and negative second-dihedron. Figs. 291-294 illustrate these forms. Fig. 293 is a basal section with $c_1(011)$ and $c_2(10\bar{1}2)$ below.

3 TRI-RHOMBOHEDRAL CLASS 22 RHENACTIP TYPE

Rhombohedral, Trigonal Rhombohedral, Rhombohedral Tetrahedral or Hexagonal Alternating Class

157. Symmetry. Vert. Ax. 3, C. This class is illustrated by the species *diprase*, *prase*, etc., which are diatomic minerals, etc., and is an important one. It is characterized by the presence of 3 planes of symmetry and the vertical axis is still devoid of trigonal symmetry, and there is a center of symmetry; cf. Fig. 245.

158. Typical Forms. The distinctive forms of the class are the rhombohedron of the second order and the hexagonal prism and rhombohedron, each of the third order. The first is characterized by three rhombohedral faces of distinct types (each + and -), and hence the name given to it.



Symmetry of Tri-Rhombohedral Class

The second-order rhombohedron may be derived by taking one half the faces of the normal hexagonal pyramid of the second order. There will be two complementary forms known as positive and negative. For example, in a given case the indices of the faces for the positive and negative forms are:

Positive (above)	$11\bar{2}$	$\bar{2}112$	$1\bar{2}12$	(below)	$\bar{1}212$	$112\bar{2}$	$211\bar{2}$
Negative (above)	$1\bar{2}12$	$112\bar{2}$	$211\bar{2}$	(below)	$121\bar{2}$	$1\bar{2}12$	$112\bar{2}$

The rhombohedron of the third order has the general symbol $\{hkl\}$, and may be derived from the normal dihexagonal pyramid, Fig. 245, by taking one quarter of the faces of the latter.

There are therefore four complementary third order rhombohedrons, distinguished respectively as positive right-handed ($2\bar{1}31$), positive left-handed ($3\bar{1}21$), negative right-handed ($\bar{1}321$), and negative left-handed ($1\bar{2}31$). The indices of the six like faces of the positive right-handed form ($2\bar{1}31$) are

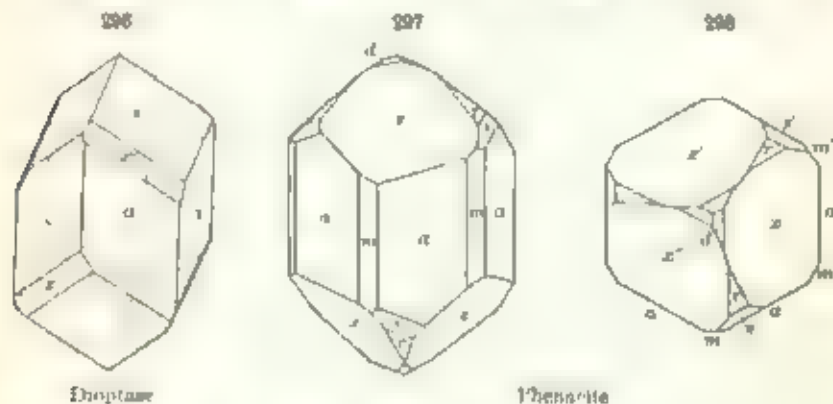
Above, $2\bar{1}31$, $\bar{3}211$, 1321 , below, $1\bar{3}2\bar{1}$, $\bar{2}1\bar{1}1$, $3\bar{1}2\bar{1}$

The *herapain* prism of the third order may be derived from the normal hexagonal prism, Fig. 235, by taking one half the faces of the latter. There are two complementary forms known as right- and left-handed. The faces of these forms in a given case, $2\bar{1}30$, have the indices

Right	$2\bar{1}30$,	$1\bar{3}30$,	$\bar{3}210$,	$2\bar{1}30$,	1320 ,	$\bar{3}\bar{1}10$
Left	1230 ,	$2\bar{3}10$,	3120 ,	$\bar{1}300$,	2310 ,	3120

159. The remaining forms are geometrically like those of the rhombohedron class viz. Basal $\{0001\}$, first order prism $m\{10\bar{1}0\}$, second order prism $a\{11\bar{2}0\}$, rhombohedrons of the first order, as $\{10\bar{1}1\}$ and $\{011\bar{1}\}$, etc.

160. The forms of this group are illustrated by Figs. 296-298. Fig. 296 is of diopside and shows the hexagonal prism of the second order $a\{11\bar{2}0\}$ with a negative first order rhombohedron $r\{10\bar{1}1\}$, and the third order rhom-



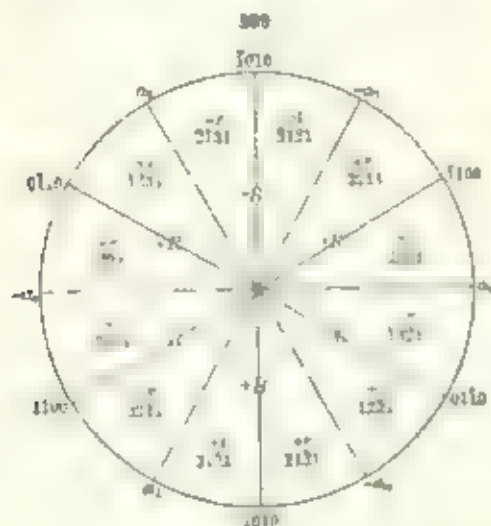
bhedron $r\{13\bar{1}1\}$. Figs. 207 and 208 show the clinographic and horizontal projections of a crystal of plumbite with the following forms: first order prism $m\{10\bar{1}0\}$, second order prism $a\{11\bar{2}0\}$, third order rhombohedrons, $r\{1232\}$ and $r\{21\bar{3}1\}$, first order rhombohedrons $r\{10\bar{1}1\}$ and $r\{011\bar{1}\}$.

In order to make clear the position of the faces of the different types of forms under this case, Fig. 299 is added. Here the zones of the positive and negative rhombohedrons of the first order are indicated ($+R$ and $-R$) also the general positions of the four types of the third order rhombohedrons ($+r$, $-r$, $+l$, $-l$).

The following scheme may also be helpful in connection with Fig. 299. It shows the distribution of the faces of the four rhombohedrons of the third order ($+r$, $+l$, $-r$, $-l$) relatively to the faces of the unit hexagonal prism ($10\bar{1}0$).

PHEASANT TYPE

$\frac{+1}{3\bar{1}\bar{2}1}$	$\frac{+r}{2\bar{1}1}$	$\frac{+s}{2\bar{3}1}$	$\frac{+t}{1\bar{2}1}$	$\frac{+l}{3\bar{1}1}$	$\frac{+r}{3\bar{2}11}$	$\frac{+l}{3\bar{1}\bar{2}1}$	$\frac{+r}{2\bar{1}\bar{3}1}$	$\frac{+s}{2\bar{3}\bar{1}1}$	$\frac{+t}{1\bar{2}\bar{1}1}$	$\frac{+r}{2\bar{3}11}$	$\frac{+s}{1\bar{2}11}$
$\frac{+1}{3\bar{1}\bar{2}1}$	$\frac{+r}{2\bar{1}1}$	$\frac{+s}{2\bar{3}1}$	$\frac{+t}{1\bar{2}1}$	$\frac{+l}{3\bar{1}1}$	$\frac{+r}{3\bar{2}11}$	$\frac{+l}{3\bar{1}\bar{2}1}$	$\frac{+r}{2\bar{1}\bar{3}1}$	$\frac{+s}{2\bar{3}\bar{1}1}$	$\frac{+t}{1\bar{2}\bar{1}1}$	$\frac{+r}{2\bar{3}11}$	$\frac{+s}{1\bar{2}11}$
$\frac{-1}{312\bar{1}}$	$\frac{-r}{21\bar{1}}$	$\frac{-s}{23\bar{1}}$	$\frac{-t}{12\bar{1}}$	$\frac{-l}{31\bar{1}}$	$\frac{-r}{32\bar{1}\bar{1}}$	$\frac{-l}{31\bar{2}\bar{1}}$	$\frac{-r}{21\bar{3}\bar{1}}$	$\frac{-s}{23\bar{1}\bar{1}}$	$\frac{-t}{12\bar{1}\bar{1}}$	$\frac{-r}{231\bar{1}}$	$\frac{-s}{121\bar{1}}$

4. TRAPEZOHEDRAL CLASS (23) α -QUARTZ TYPE

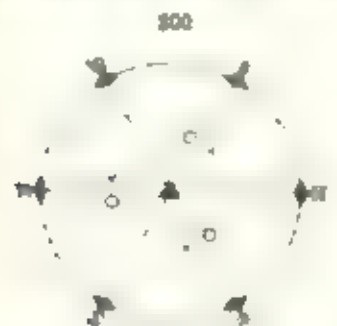
(Trigonal Trapezohedra, Trapezohedral Tetartohedra, or Trigonal Helical Class)

161 Symmetry. Vert. Ax.-3; 3 hor. Ax.-2. This class includes, among numerous, the species quartz and calcite. The forms have no plane of symmetry and no center of symmetry; the vertical axis is, however, an axis of trigonal symmetry, and there are also three *secondary* axes of binary symmetry, each lying in direction with the crystallographic axes of Fig. 300.

162. Typical Forms. The characteristic form of this class is the trigonal trapezohedron shown in Fig. 301. This is the general form corresponding to the symbol $2\bar{3}$, the faces being represented as indicated in the accompanying stereographic projection, Fig. 302. The faces of this form correspond to six of the faces of the regular hexagonal pyramid, Fig. 244. There are, therefore, four such trapezohedrons, two positive called respectively right-handed (Fig. 301) and left-handed (Fig. 302) and two similar negative forms, also right- and left-handed, see the scheme given in Art. 164. It is obvious that the two forms of Figs. 301, 302 are enantio-

morphous, and circular polarization is a striking character of the species belonging to the class as elsewhere discussed.

The indices of the six faces belonging to each of these will be evident on consulting Figs. 300, 247 and 248. The complementary positive form (r and h) of a given symbol, near to the twelve faces of a positive sphenohedron, where the faces of all four as a ready stated include the twenty-four faces of the dihexagonal pyramid.



Symmetry of Trapezohedral Class



Trapezohedron



Corresponding to these trapezohedrons are two *trigonal prisms*, respectively right- and left-handed, as (2130) and (1230).

The remaining characteristic forms are the right- and left-handed *trigonal prisms* (1120) and (2110), also the right- and left-handed *trigonal pyramids* as (1122) and (2112). They may be derived by taking respectively one half the faces of the hexagonal prism, of the same order (1120) or of the corresponding pyramid (1122). These are shown in Figs. 239 and 241.

163. Other Forms. The other forms of the class are geometrically like those of a normal rhombohedral class. They are the base (0001), the hexagonal first order prism ($01\bar{1}$), and the positive and negative rhombohedrons as (011) and (011). These can not be distinguished geometrically from the normal forms.



Figs. 303-307, Quartz

164. Illustrations. - The forms of this class are best shown in the species quartz. As already remarked (p. 122), simple crystals often appear to be

167. Axial and Angular Elements. The axial element is the length of the vertical axis, c , in terms of a horizontal axis, a , or other way, the axial ratio of c to a is given as c/a . The angular element is the angle between the base (0001) and the prism, which is $\angle(0001 \wedge 10\bar{1}1)$ or $\angle(0001 \wedge 112)$.

The angular element is also given by the angle between the base (0001) and the prism, which is $\angle(0001 \wedge 10\bar{1}1)$ or $\angle(0001 \wedge 112)$.

The axial ratio, c/a , and the angle, $\angle(0001 \wedge 10\bar{1}1)$, are given by the formula

$$\tan (\angle 0001 \wedge 10\bar{1}1) \times \frac{1}{2} \sqrt{3} = c/a$$

The vertical axis is also easily obtained from the angular element, since

$$\tan (\angle 0001 \wedge 112) = c/a$$

These results are made general by writing them as follows

$$\tan (\angle 0001 \wedge h0\bar{h}l) \times \frac{1}{2} \sqrt{3} = \frac{h}{l} \times c/a$$

$$\tan (\angle 0001 \wedge hkh2h) = \frac{2h}{l} \times c/a$$

In general, it is easy to obtain any required angle between the poles of two faces of the crystal, simply by using the sine of the angle of inclination of the faces to the horizontal, or by the application of spherical trigonometry. The exact measurement of the angles is made by using a goniometer.

168. Tangent and Cotangent Relations. The tangent form is also good in any zone from (0001) to a face of a prismatic zone. For example,

$$\begin{aligned} \tan (\angle 0001 \wedge 00h) &= h/a & \tan (\angle 0001 \wedge hkh2h) &= 2h/a \\ \tan (\angle 0001 \wedge 10\bar{1}1) &= 1/2 & \tan (\angle 0001 \wedge 112) &= c/a \end{aligned}$$

In the prismatic zone, the cotangent form is taken as a preferable form. For example, for a dihexagonal prism $(10\bar{1}0)$ and (1120)

$$\cot (\angle 10\bar{1}0 \wedge hkh) = \frac{2h}{1} \times \frac{1}{\sqrt{3}}$$

$$\cot (\angle 1120 \wedge hkh) = \frac{h}{h} \times \frac{1}{\sqrt{3}}$$

The value of the angles $\angle(10\bar{1}0 \wedge hkh)$ and $\angle(1120 \wedge hkh)$ may be found.

For the prismatic zone, the writing of a zone general form is due to any particular face, which may be chosen. If $(10\bar{1}0)$ and a face of the zone (0001) , (1120) , where $h = k$, are taken as the zone poles, then the zone general form is (hkh) . If the face $(10\bar{1}0)$ and a face of the zone (1120) are taken as the zone poles, then the zone general form is (hkh) . If the face $(10\bar{1}0)$ and a face of the zone (1120) are taken as the zone poles, then the zone general form is (hkh) . If the face $(10\bar{1}0)$ and a face of the zone (1120) are taken as the zone poles, then the zone general form is (hkh) .

$$\cot (\angle 10\bar{1}0 \wedge hkh) = \cot (\angle 10\bar{1}0 \wedge 112) \times \frac{2h}{1}$$

and

$$\cot (\angle 1120 \wedge hkh) = \cot (\angle 1120 \wedge 10\bar{1}1) \times \frac{h}{h}$$

Also similarly for other zones,

$$\cot (\angle 10\bar{1}0 \wedge hkh) = \cot (\angle 10\bar{1}0 \wedge 02\bar{2}1) \times \frac{2h}{1} \times \frac{1}{\sqrt{3}} \text{ etc.}$$

$$\cot (\angle 1120 \wedge hkh) = \cot (\angle 1120 \wedge 20\bar{2}1) \times \frac{h}{h} \times \frac{1}{\sqrt{3}} \text{ etc.}$$

2. The distance PQ between the poles of any two faces $P(hkl)$ and $Q(pqr)$ is given by the equation

$$\cos PQ = \frac{3c^2 + 2a^2(hq + pk) + 2b^2p + 2kq}{4a^2p^2 + 4a^2h^2 + k^2 + 4b^2k^2 + 4c^2(p^2 + q^2 + r^2)}$$

3. For special cases the above formula becomes simplified. It serves to give the value of the angle α , β , γ for the several forms in the system. They are as follows:

(a) *Pyramid of First Order* (hkl) (Fig. 242)

$$\cos X \text{ (terminal)} = \frac{k}{3p^2 + 4hk^2} \quad \cos Z \text{ (basal)} = \frac{4h^2}{h^2 + 4hk^2}$$

(b) *Pyramid of Second Order* ($hkh2h$) (Fig. 243)

$$\cos Y \text{ (terminal)} = \frac{p}{p^2 + 4hk^2} \quad \cos Z \text{ (basal)} = \frac{4hk^2 - p^2}{p^2 + 4hk^2}$$

(c) *Dihedral Pyramid* (hkl)

$$\cos X \text{ (see Fig. 244)} = \frac{3p^2 + 2c^2(h^2 + k^2 + 4hk)}{4p^2 + 4c^2(h^2 + k^2 + hk)}$$

$$\cos Y \text{ (see Fig. 244)} = \frac{3p^2 + 2c^2(2h^2 + 2hk + k^2)}{3p^2 + 4c^2(h^2 + k^2 + hk)}$$

$$\cos Z \text{ (basal)} = \frac{4c^2(h^2 + k^2 + hk) - 3p^2}{3p^2 + 4c^2(h^2 + k^2 + hk)}$$

(d) *Dihedral Prism* ($hkl0$) (Fig. 245)

$$\cos X \text{ (axial)} = \frac{h^2 + k^2 + 3hk}{2(h^2 + k^2 + hk)} \quad \cos Y \text{ (diagonal)} = \frac{2h^2 + 2hk - k^2}{2(h^2 + k^2 + hk)}$$

(e) *Rhombohedral* ($10\bar{1}1$)

$$\cos X \text{ (terminal)} = \frac{3p^2 - 2k^2}{3p^2 + 4hk^2}$$

(f) *Scalenohedron* (hkl):

$$\cos X \text{ (see Fig. 277)} = \frac{3p^2 + 2c^2(2k^2 + 2hk - h^2)}{4p^2 + 4c^2(h^2 + k^2 + hk)}$$

$$\cos Y \text{ (see Fig. 277)} = \frac{4p^2 + 2c^2(2h^2 + 2hk - k^2)}{3p^2 + 4c^2(h^2 + k^2 + hk)}$$

$$\cos Z \text{ (basal)} = \frac{2c^2(h^2 + k^2 + 4hk) - 3p^2}{4p^2 + 4c^2(h^2 + k^2 + hk)}$$

172. Angles. The angles for some commonly occurring rhombohedral prisms with the first and second order pyramids are given in the following table:

	$m(1010)$	$a(1120)$
61°50'	8° 57'	21° 3'
11°50'	10° 31'	10° 04'
31°41'	13° 4'	15° 6'
52°20'	16° 6'	13° 54'
21°30'	10° 04'	10° 53 1/2'
11°50'	2° 24'	0° 35 1/2'
63°00'	20° 14'	3° 40'

173. The Miller Axes and Indices.—The forms of the hexagonal system were referred by Miller to a set of three principal axes which were chosen parallel to the edges of the unit rhombohedral prism of the species. (Fig. 309) represents such a rhombohedron with the orientation of the Miller axes shown. If a plane of faces is to be assigned to it as has the place of position that is, several cases the faces of the same form are represented by two sets of different indices. For example, the faces of the α crystal of the first part would give the numbers, 100, $\pm 2\bar{1}$, ± 10 , ± 22 , 001, ± 12 . Thus, in fact, however, many faces of the Miller axes

Miller indices are used only for forms in the Hexagonal Division, that is, for forms belonging to classes which are characterized by a vertical axis of trigonal symmetry. It is believed, however, that the mutual relations of all the members of both divisions of the hexagonal system among themselves, as also to the members of the trigonal system, both morphological and physical, are so intimate that they may be brought into the same perspective. This is done in Art. 135. The Miller indices, however, were not used in this part of the work, and the forms are designated by the numbers of the forms in the hexagonal system. The Miller indices are given in parentheses.

The forms are designated by the numbers of the forms in the hexagonal system. The Miller indices are given in parentheses. The forms are designated by the numbers of the forms in the hexagonal system. The Miller indices are given in parentheses.



Miller and Miller-Bravais indices Compared

that forms in the hexagonal system have the indices 100, 010, and 001 as the three of the negative (non-half) indices have 101, 011, 101. The first order prism of the hexagonal system is represented by 101, etc., while the second order prism has 101, etc. The rhombohedral pyramid

There are also three unlike planes of symmetry at right angles to each other in which are the crystallographic axes.

The symmetry of the class is exhibited in the accompanying stereographic projection (Fig. 315). This should be compared with Fig. 109 (p. 69) and Fig. 185 (p. 93), representing the symmetry of the normal classes of the isometric and tetragonal systems respectively. It will be seen that while normal isometric crystals are developed alike in the three axial directions, those of the tetragonal type have a like development only in the direction of the two horizontal axes, and those of the orthorhombic type are unlike in the three axial directions. Compare also Figs. 110 (p. 71), 189 (p. 95) and 316 (p. 140).

180. Forms. The various forms possible in this class are as follows:

	Indices
1. Macropinacoid or <i>a</i> -pinacoid	(100)
2. Brachypinacoid or <i>b</i> -pinacoid	010
3. Base or <i>c</i> -pinacoid	(001)
4. Prism	(h \bar{a} 0)
5. Macrodome	(h0l)
6. Brachydome	(0kl)
7. Pyramids	(hkl)



In general, as defined on p. 47, a *pinacoid* is a form whose faces are parallel to two of the axes; that is, a *macropinacoid*, a *prism* is one whose faces are parallel to the vertical axis, and intersect the two horizontal axes, a *brachypinacoid* is one whose faces are parallel to one of the horizontal axes, but intersect the vertical axis. A *pyramid* is a form whose faces meet all the three axes.

These terms are used in the above sense not only in the orthorhombic system, but also in the monoclinic and triclinic systems; in the last each form consists of two planes only.

181. Pinacoids. The *macropinacoid* includes two faces, each of which is parallel both to the macro-axis *b* and to the vertical axis *c*; their indices are respectively 100 and $\bar{1}00$. This form is uniformly designated by the letter *a*, and is conveniently and briefly called the *a*-face or the *a*-pinacoid.

The *brachypinacoid* includes two faces, each of which is parallel both to the brachy-axis *a* and to the vertical axis *c*; they have the indices 010 and $0\bar{1}0$. This form is designated by the letter *b*; it is called the *b*-face or the *b*-pinacoid.

The *base* or *basal pinacoid* includes the two faces parallel to the plane of the horizontal axes, and having the indices 001 and $00\bar{1}$. This form is designated by the letter *c*; it is called the *c*-face or the *c*-pinacoid.

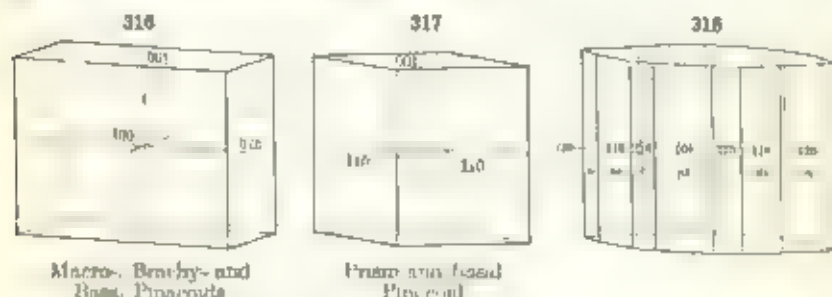
Each one of these three pinacoids is an open-form; but together they make the so-called *diametral prism*, shown in Fig. 316, a solid which is the analogue of the cube of the isometric system. Geometrically it cannot be distinguished from the cube, but it differs in having the symmetry unlike in the three axial directions (this may be shown by the make physical character of the axes *a*, *b*, *c*, for example as in *linnet*, *stratians*, etc., or, again, by the cleavage). Further, it is proved at once by optical properties. This

* From the Latin *domus* because resembling the roof of a house, cf. Figs. 310, 320.

† See p. 48.

diametral prism, as just stated, has three pairs of unlike faces. It has three kinds of edges, four in each set parallel respectively to the axes a , b , and c ; it has further eight similar solid angles. In Fig. 316 the dimensions are arbitrarily made to correspond to the relative lengths of the chosen axes, but the student will understand that a crystal of this shape gives no information as to these values.

182. Prisms. The prisms proper include those forms whose faces are parallel to the vertical axis, while they intersect both the horizontal axes. Their general symbol is, therefore, $chab$. These all belong to one type of *rhombic prism* in which the interfacial angles corresponding to the two unlike vertical edges have different values.



The *unit prism* (110) is that form whose faces intersect the horizontal axes in lengths having a ratio corresponding to the selected axial ratio of a : b for the given species. In other words, the angle of this unit prism fixes the unit lengths of a and b horizontal axes. This form is shown in relation with the basal pinacoid in Fig. 317; it is universally designated by the letter u . The four faces of the unit prism have the indices 110, $\bar{1}10$, $\bar{1}\bar{1}0$, $1\bar{1}0$.

There are, of course, a large number of other possible prisms whose intercepts upon the horizontal axes are not proper or else to their unit lengths. These may be divided into two classes as follows: *macroprisms*, whose faces are between those of the macroprism and the unit prism; *brachyprisms* whose faces lie between those of the brachyprism and the unit prism. A macroprism has the general symbol hka in which $h > k$ and is represented by a (cf. Fig. 210), Fig. 318. A brachyprism has the general symbol $chab$ with $h < k$ and is represented by a (200) (Fig. 318).

183. Macrodomes, Brachydomes. The *macrodomes* are forms whose faces are parallel to the macro-axis b while they intersect the vertical axis c and the horizontal axis a . Hence the general symbol is chc . The angle a : ac and macrodome, chc , fixes the ratio of the axes a : c . The form is shown in Fig. 319 combined with u per form with the basal pinacoid.

In the macrodome u (between the base $a(001)$ and the macroprism $a(100)$ there may be a large number of macrodomes having the symbols, taken in the order named: 101, 102, 203, 104, 302, 201, 301, etc., cf. Figs. 336 and 347 described later.

The *brachydomes* are forms whose faces are parallel to the brachy-axis a , while they intersect the other axes c at b ; their general symbol is $0bc$. The angle of the unit brachydome (011), which is shown with $a(100)$ in Fig. 320, determines the ratio of the axes b : c .

The brachydome zone between $c(001)$ and $b(010)$ includes the forms 013, 1012, 023, 011, 032, 021, 031, etc. cf Figs. 336 and 337.

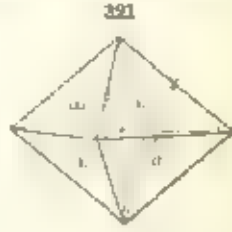
Both sets of domes are often spoken of as *horizontal prisms*. The propriety of this expression is obvious, since they are in fact prisms in geometrical form, further the choice of position for the axes which makes them forms, instead of prisms in the narrower sense, is more or less arbitrary, as already explained.



Macrodome and
Brachyparacoid



Brachydome
and Macroparacoid



Pyramid

184. Pyramids. The pyramids in this system all belong to one type, the double *rhombic pyramid*, as it is called by eight faces, each a scalene triangle. This form has three kinds of edges, x, y, z (Fig. 321) each set with a differential vertical angle; two of these angles suffice to determine the axial ratio. The symbol for this the general form for the system is hkl .

The pyramids may be divided into three groups corresponding respectively to the three prisms just described: unitary, unit pyramids, macropyramids and brachypyrramids.

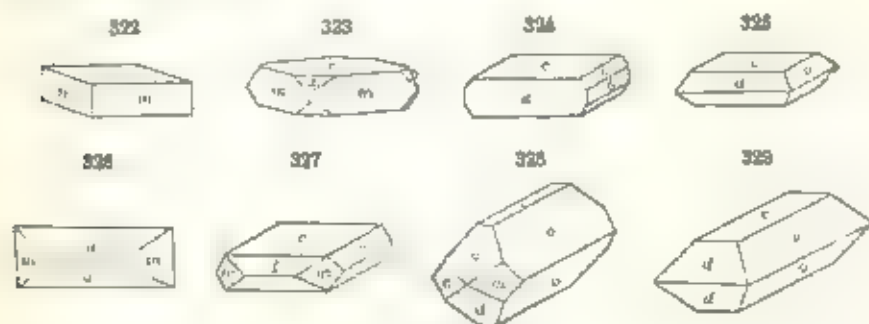
The *unit pyramids* are characterized by the fact that their intercepts on the horizontal axes have the same ratio as those of the unit prism; that is, the assumed axial ratio $a : b$ for the given species. For them, therefore the general symbol becomes hkl .

There may be different unit pyramids on crystals of the same species with different intercepts upon the vertical axis and these form a zone of faces lying between the base $c(001)$ and the unit prism 010 ; this zone would include the forms, $111, 11\bar{1}, 112, 11\bar{2}, 113, 11\bar{3}$. In the symbol of any of the forms of this zone $h = k$ and the lengths of the vertical axes are here in the example given, $\frac{1}{2}, \frac{1}{3}, \frac{1}{4}$ of the vertical axis c of the unit pyramid.

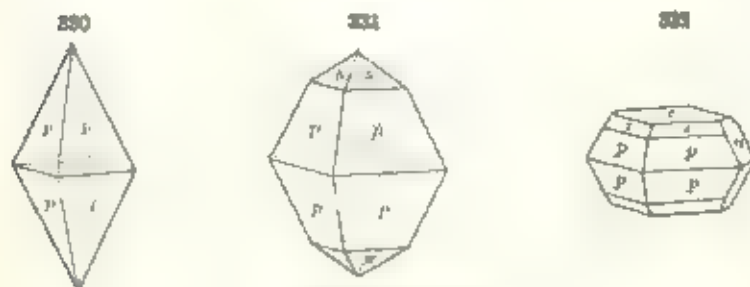
The *macropyramids* and *brachypyrramids* are related to each other and to the unit pyramids, as were the macroprisms and brachyprisms to their bases and to the unit prism. Every unit vertical zone of macropyramids (or brachypyrramids) having a common ratio for the horizontal axes (or $a : b$ in the symbol) belongs to a particular macroprism (or brachyprism) characterized by its symbol. Thus the macropyramids $211, 21\bar{1}, 212, 21\bar{2}$, etc., belong to a common vertical zone between the base $c(001)$ and the prism 010 . Similarly the brachypyrramids $123, 12\bar{2}, 121, 12\bar{1}$, etc. belong to a common vertical zone between $c(001)$ and 010 .

185. Illustrations. The following figures of barite (322-326) give excellent illustrations of crystals of a type which under species, and show also how the habit of one and the same species may vary. The axial ratio for this species is $a : b : c = 0.815 : 1 : 1.311$. Here a is the macrodome

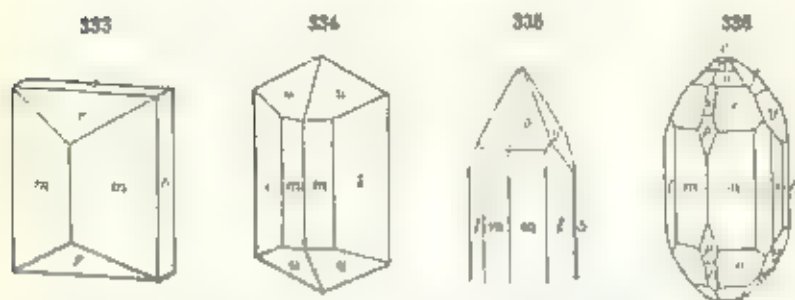
(102) and o the brachydome (011), m is, as always, the prism (110). Figs. 322, 323 and 327 are described as tabular $o(01)$. Fig. 326 is prismatic in habit in the direction of the m -axis (b) and Figs. 328, 329 prismatic in that of the brachy-axis (a).



Barite Crystals



Sulphur Crystals



Figs. 334-336, Topaz

Staurolite

Figs. 330-332 of native sulphur show a series of crystals of pyramidal habit with the dome $m(011)$, and the pyramids $p(111)$, & $r(11\bar{1})$. Note n marks the terminal edges of the four-sided pyramid p . In general, it should

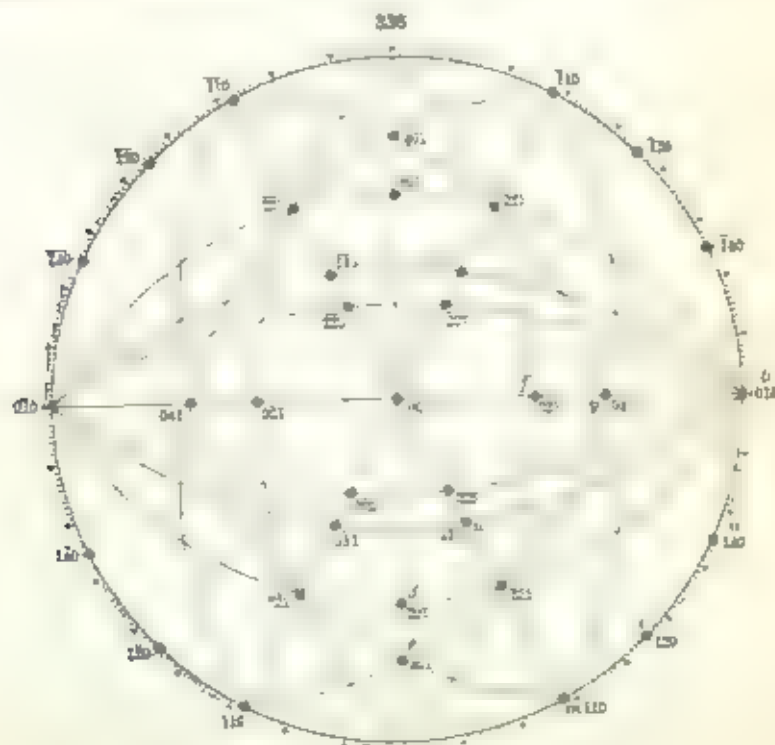
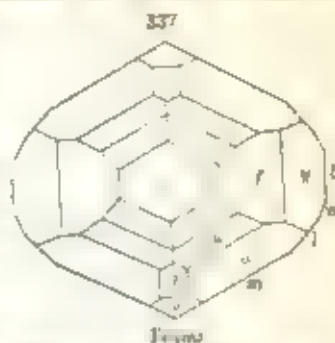
be remembered that a macrodome truncating the edge of a pyramid must have the same ratio of $h : l$ as 201 truncates the edge of 221 , etc. Similarly if the brachydome 021 truncates the edge of 221 , etc. of Figs. 337-339.

Again Fig. 333 of staurolite shows the pinacoids $h010$, $c001$, the prism $m110$ and the macrodome $r401$.

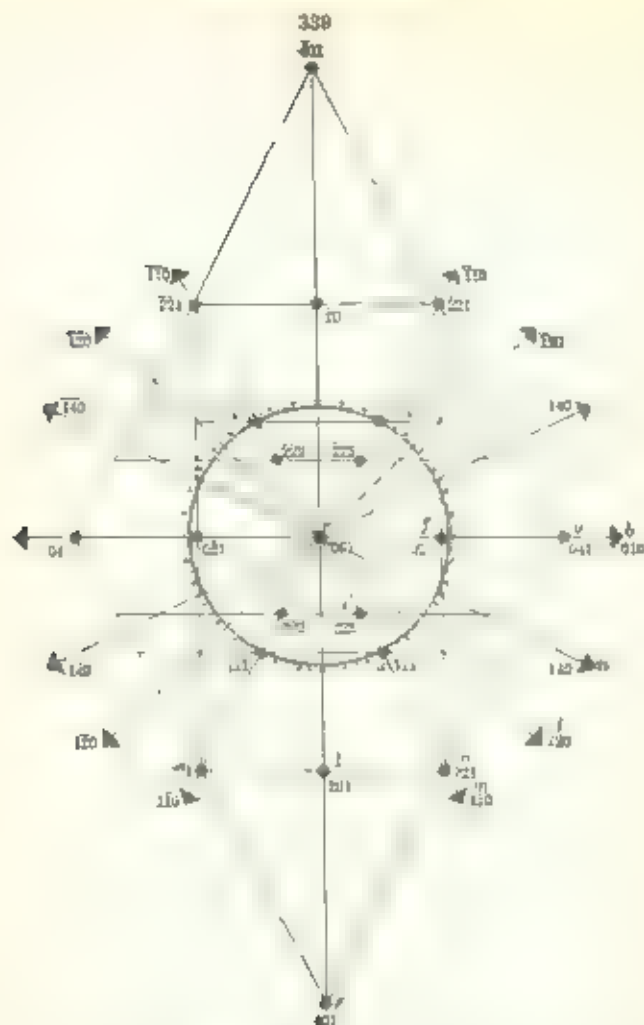
Figs. 334-336 are prismatic crystals of topaz. Here m is the prism 110 , l and l' are the prisms 120 , 140 , a and a' are the macrodomes 201 and 401 , β and β' are the brachydomes 021 and 041 , γ , δ and ϵ are the pyramids 223 , 411 , 221 .

186. Projections. - Both stereographic and gnomonic projections are given in Figs. 337-339 for a crystal of the species *topaz*.

Fig. 337 is the basal projection of the crystal shown in Fig. 334. Figs. 338 and 339 give the stereographic and gnomonic projections of the forms present upon it.



Stereographic Projection Topaz Crystal



Gnomonic Projection Topaz Crystal

2. HEMIMORPHIC CLASS 26 (ALAMINE TYPE)

Orthorhombic Pyramidal or Uniaxial Polar Class

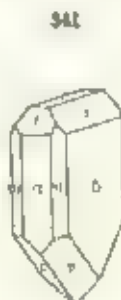
187 Class Symmetry and Typical Forms. Vert. Ax.-2; 2 vert. xl. P.

The forms of the *orthorhombic-hemimorphic* class are characterized by two principal planes of symmetry at right angles to each other, the vertical axis of symmetry, the base in which they intersect, there is no center of symmetry. The forms are therefore hemimorphic, as defined in Art. 28. For example, if ax is usually the case, the vertical axis is made the axis of symmetry, the two planes of symmetry

are parallel to the prisms, $a(100)$ and $b(010)$. The prisms are then geometrically like those of the normal class, as are also the macroprism and brachyprism, but the two basal planes (or pedions) occur in tetragonal form (001 and $\bar{0}\bar{0}\bar{1}$). There are also two macrodomes, 101 and $\bar{1}\bar{0}\bar{1}$, or in general $h0l$ and $\bar{h}0\bar{l}$, and similarly two sets, for a given symbol, of brachydomes and pyramids.



Symmetry of Rhombic Class



Calamine



Struvite

The general symmetry of the class is shown in the stereographic projection Fig 340. Further Figs 341, of calamine, and 342, of struvite, represent typical crystals of this class. In fig 341, the forms present are $h(101)$, $a(010)$, $c(001)$, in fig 342 they are $a(101)$, $a(101)$, $c(001)$.

3 SPHENOIDAL CLASS (27) EPSOMITE TYPE

(Orthorhombic Disphenoidal or Diagonal Holaxial Class)

188. Symmetry and Typical Forms. 3 xl. Ar -2. — The forms of the remaining class of the system, the *orthorhombic-sphenoidal* class, are characterized by three unlike rectangular axes of binary symmetry which coincide with the crystallographic axes, but they have no plane and no center of symmetry (Fig 343). The general form hkl here has four faces only, and the corresponding solid is a rhombic sphenoid, analogous to the sphenoid of the tetragonal system. The complementary positive and negative sphenoids are enantiomorphous. Fig 344 represents a typical crystal of epsomite, with the positive sphenoid, $a(111)$. Other crystals of this species often show both positive and negative complementary forms, but usually unequally developed.



Symmetry of Sphenoidal Class



Epsomite

MATHEMATICAL RELATIONS OF THE ORTHORHOMBIC SYSTEM

189. Choice of Axes. As explained in Art. 179, the three crystallographic axes are first determined by inspection of the crystal, and then the axes are chosen so that the vertical axis, and all of the other axes, are at right angles to the faces of the crystal. The axes are then chosen so that the vertical axis is at right angles to the faces of the crystal, and the other axes are at right angles to the faces of the crystal.

If the crystal is given, the axes are chosen so that the vertical axis is at right angles to the faces of the crystal, and the other axes are at right angles to the faces of the crystal. The axes are then chosen so that the vertical axis is at right angles to the faces of the crystal, and the other axes are at right angles to the faces of the crystal.

190. Axial and Angular Elements. The axial elements are given by the ratio of the lengths of the three axes in respect to the macrocrystal. For example with barite the axial ratio is

$$a : b : c = 0.81520 : 1 : 1.01359$$

The angular elements are usually given as the angles between the three pinacoids and the unit axes or the three zones between them. Thus again for barite, these elements are

$$100 \wedge 110 = 39^\circ 11' 43'' \quad 001 \wedge 101 = 59^\circ 40' 35'' \quad 001 \wedge 011 = 52^\circ 45' 4''$$

Two of these angles obtained determine the third angle as well as the axial ratio. The degree of accuracy of the angles and the axial ratio of the crystal is a good test of the quality of the crystal. The angles are usually given to the nearest minute. There is no need to give the angles to the nearest second. In the above cases the measurements are given to the nearest minute. The axial ratio is given to the nearest five decimal places. It is not necessary to have the angles to the nearest second, but it is better to have the angles to the nearest minute, so that the calculated angles are not far from the actual angles from those given, direct from the measured angles by means of the trigonometric functions.

191. Calculation of the Axes. The following simple relations (cf. Art. 63) connect the axes with the angular elements:

$$\tan 100 \wedge 110 = a, \quad \tan 001 \wedge 011 = c, \quad \tan 001 \wedge 101 = \frac{c}{a}$$

These equations serve to give either the axes from the angular elements, or the angular elements from the axes. They show that the axes are not needed for the calculation of the angular elements, but they are needed to have them for example to use in calculating the angular elements from the axes.

In the above cases the angles are measured angles, measured on the basis of the crystal, or on the basis of the macrocrystal. The angles are measured on the basis of the crystal, or on the basis of the macrocrystal. The angles are measured on the basis of the crystal, or on the basis of the macrocrystal.

Thus if we know the three zones 100 and 101 and 010 and 100, 101 and 110. For the angles 100 and 101, the angles are 100 and 101, and the angles are 100 and 101. The angles are 100 and 101, and the angles are 100 and 101.

$$\tan (001 \wedge 302) = \frac{c}{a} \times \tan (001 \wedge 101),$$

$$\tan (001 \wedge 011) = \frac{c}{a} \times \tan (001 \wedge 101), \quad \tan (100 \wedge 310) = \frac{c}{a} \times \tan (100 \wedge 110)$$

192. Example. Fig. 34 represents a crystal of barite (from Japan) and Fig. 34b the macrocrystal. The angles of the crystal are 100 and 101 and 010 and 100, 101 and 110. The angles are 100 and 101, and the angles are 100 and 101.

$$\tan' (363 \wedge 353) = 55^\circ 1' 0'',$$

$$\tan'' (363 \wedge 353) = 20^\circ 38' 0'',$$

Hence the angles 363 and 353 are 55° 1' 0" and 20° 38' 0" are known without aid of the trigonometric functions. The angles are 55° 1' 0" and 20° 38' 0" are known without aid of the trigonometric functions.

* The student should draw a projection of Fig. 34b and determine the angles between the faces of the crystal, and show that only approximately, the relative position of the faces present.

But $\tan (001 \wedge 011) = \frac{1}{2} \times \tan (001 \wedge 010) = 0.55$ and $\tan (001 \wedge 011) = c$. Also, since $\tan (001 \wedge 101) = \frac{1}{3}$, the axial ratio is thus known, and two of the angular elements.

The third angular element, $001 \wedge 111$, can be calculated independently for the angle at 001 in the triangle $001 \wedge 111 \wedge 101$ equal to $100 \wedge 110$ and $\tan 011 = 0.55 \times \frac{1}{2} = 0.10 \wedge 110$, the complement of $100 \wedge 110$.

Then since $\tan 100 \wedge 110 = 0.55$, this can be used to check the value of c already obtained. The further use of the trigonometric principle with the corresponding sides of a right-angled triangle will serve to give an indirect angle from either the fundamental angles about c or a , the a axis elements.

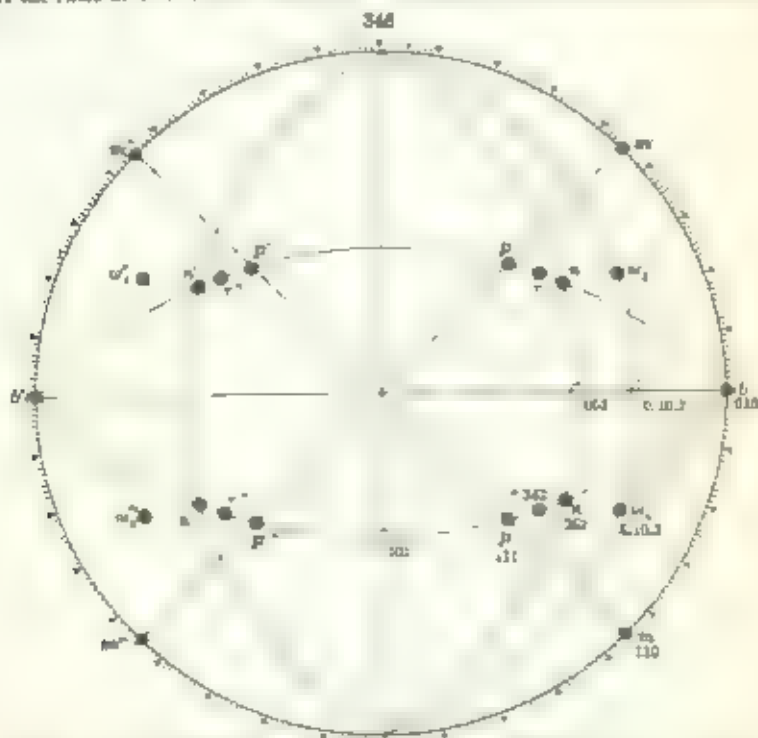
Again, the value of any distance can be readily calculated if two measured angles of considerable accuracy are at hand. For example, on the face a , suppose the measured angles to be

$$\text{for } (010 \wedge hkl) = 30^\circ 15', \quad \text{and } (010 \wedge khl) = 51^\circ 32'$$

The solution of the triangle $h-k-0kl$ gives the angle $(010 \wedge 0kl) = 16^\circ 25' 30''$, and

$$\frac{\tan (010 \wedge 0kl)}{\tan (0kl \wedge hkl)} = \frac{\tan 16^\circ 25' 30''}{\tan 51^\circ 32'} = 0.333 \pm, = \frac{h}{k}$$

But the ratio of $h : k$ must be rational and the number derived agrees most closely with $\frac{1}{3}$.



Stereographic Projection of Crystal Faces

Again, the angle $001 \wedge 101$ may now be calculated from the same triangle and the value $59^\circ 48'$ obtained. From this the ratio of $a : c$ is therefore

$$\frac{\tan (001 \wedge 101)}{\tan (001 \wedge 011)} = \frac{\tan 59^\circ 48'}{\tan 30^\circ 15'} = 1.945 = \frac{a}{c}$$

This ratio is nearly equal to 5:3, and the two values thus obtained give the symbol 5:10:3. If, however, from the triangle $O'c'ab'$, the angle at O' is calculated, the value of $\frac{b}{a}$ is obtained, which gives the angle $31.0^\circ \wedge 11.0^\circ$. From this the ratio $\frac{b}{c}$ is deduced since

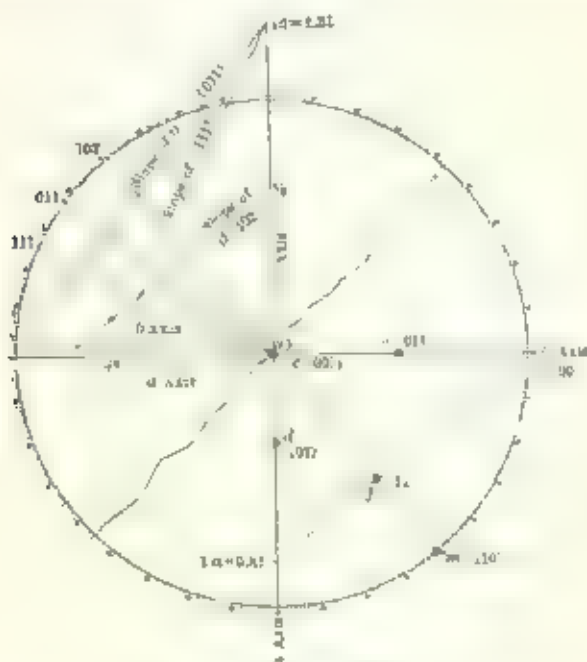
$$\frac{\tan 45^\circ 12' }{\tan 36^\circ 42' } = \frac{b}{c} = 2.002 = \frac{b}{c}$$

The value of $\frac{b}{c}$ is hence closely equal to 2, thus combined with that first obtained $\left(\frac{b}{a} = \frac{5}{3}\right)$ gives the same symbol 5:10:3.

This somewhat tedious manner than usually employed calls for fairly accurate measurements. However, since the symbol obtained is rational, it may be compared with the measurements with these rational data, from the symbol. For example, in the given case the calculated angles for $a = 100$ are $\angle(011) = 10.3^\circ$ and $\angle(110) = 31.0^\circ$. The correctness of the value obtained is further established if it is found that the given face is a $\{110\}$ prismatic zone.

It will be mentioned further that the zonal relations, explained on pp. 61-64, play an important part in calculations. For example, in Fig. 345 if the symbol of r were unknown, it could be obtained from a single angle (as before), since for this zone $h = l$.

345



Determination of the Axial Ratio for Barite

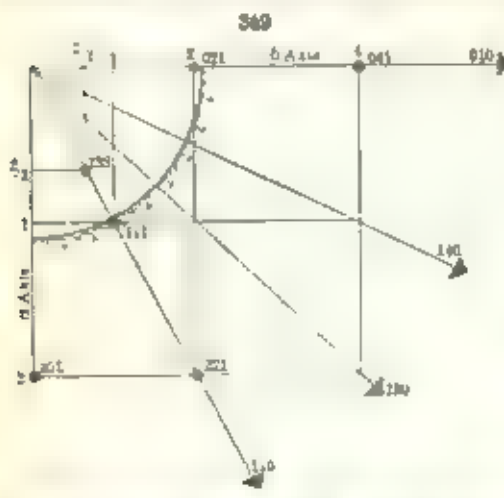
123. Formulas. Although it is not often necessary to employ formulas in explanation, a few are added here for sake of completeness. Here a and c in the formulas are the lengths of the two axes a and c .

(1) For the distance between the pole of any face $P(hkl)$ and the pinacoids a , b , c we have in general

$$\cos^2 PC = \cos^2 hkl \wedge (100) = \frac{h^2 c^2}{h^2 c^2 + k^2 a^2 + l^2 c^2}$$

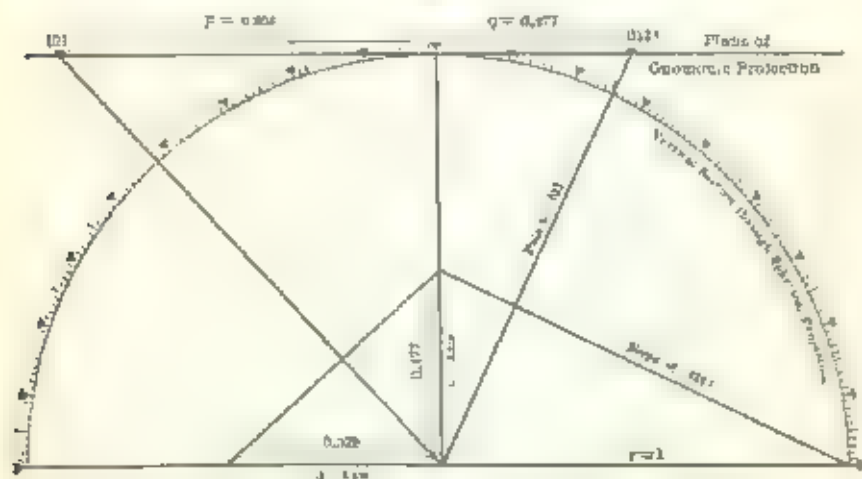
mal to the face is determined by measuring with a protractor the angular distance between them (Fig. 349). The line giving the slope of the face is next drawn perpendicular to this normal

and its intercept upon the line representing the vertical axis determined. This distance when expressed in terms of the length of the b axis is 0.45. This is twice the established length of the c axis (0.475) and consequently the third parameter of the form q is 2c. This gives the indices 22, for the face.



put it in as required for each face. A convenient intercept upon each of the two axes as 1 gives the intercepts upon the axes when expressed in terms of this length. If the value of q is not a whole number, the form is one already had indices assigned to them the q series that shall be counterbalanced by c to base.

350



If we take as equivalent to the radius of the fundamental circle of the projection, q as equal to the chosen intercept upon the b axis (logarithmic axis) and p that upon the c axis, then the axial ratio can be derived from the following expressions:

$$q = c; \quad \frac{a}{c} = \frac{r}{p}.$$

The proof of these relationships is similar to that already given under the Tetragonal System Art. 121, p. 109 and is illustrated in Fig. 350 for the case of topaz. The position of the pole of the face 011 is shown on the right end of the tangential line representing the plane of the gnomonic projection. The line giving the slope of 011 is at right angles to the pole and its intersection upon the line representing the vertical axis gives the unit length of that axis. The two right-angle triangles shown on the right-hand side of the figure are similar and a and c axes. Similarly on the left-hand side of the figure the position of the pole to the face 101 is shown and the line giving the slope of that face intersecting the c axis will determine the c axis representing the axis at unit length. The two right-angle triangles on the left side of the figure are similar and therefore the values of a and c are proportional to a and c .

197 To determine, by plotting the indices of a face upon an orthorhombic crystal, given the position of its pole upon the gnomonic projection and the axial ratio of the mineral — The method of construction in this case is the reverse of that given in the problem above and is essentially the same as given under the Isometric and Tetragonal Systems Arts. 88 and 122. In the case of an orthorhombic mineral the intercepts of the perpendiculars drawn from the pole of the face to the a and b axes must be expressed in each case in terms of the unit intercept on each axis. These values, p and q , can be determined from the equations given in the preceding problem.

V MONOCLINIC SYSTEM

(Oblique or Monosymmetric System)

198. Crystallographic Axes. — The *monoclinic system* includes all the forms which are referred to three unequal axes, having one of their axial inclinations oblique.

The axes are designated as follows: the inclined or clin-axis is a ; the ortho-axis is b , the vertical axis is c . The acute angle between the axes a and c is represented by the letter β ; the angles between a and b and b and c are right angles. See Fig. 351. When properly orientated the inclined axis, a , slopes down toward the observer, the b axis is horizontal and parallel to the observer and the c axis vertical.



Crystals. Axes of Orthorhombic
 $a : b : c = 0.966 : 1 : 0.55 \quad \beta = 94^\circ$



Symmetry of Normal Class

1 NORMAL CLASS (28) GYPSUM TYPE

(Prismatic Holohedral, or Diagonal Equatorial Class)

199 Symmetry. h xl. $Ax-2$; $a-c$ xl. P ; C . — In the normal class of the monoclinic system there is no plane of symmetry and one axis of binary symmetry normal to it. The plane of symmetry is always the plane of the

axes a and c and the axis of symmetry coincides with the axis b , normal to this plane. The position of our axis b and that of the plane of the other two axes a and c is thus fixed by the symmetry, but the latter axes may occupy different positions in this plane. Fig. 352 shows the typical stereographic projection, projected on the plane of symmetry. Figs. 367-368 are the projections of an actual crystal of epidote, here, as is usual, the plane of projection is normal to the prismatic zone.

200 Forms. The various forms* belonging to this class with their symmetries, are given in the following table. As more particularly explained later, an orthodome includes two faces only, and a pyramid four only.

	Symbols
1. Orthopinacoid or a-pinacoid	$\{100\}$
2. Clinopinacoid or b-pinacoid	$\{010\}$
3. Base or c-pinacoid	$\{001\}$
4. Prism	$\{hkl\}$
5. Orthodome	$\{hkl, \bar{h}\bar{k}l\}$
6. Clinodome	$\{0kl, 0\bar{k}l\}$
7. Pyramid	$\{hkl, \bar{h}\bar{k}l, h\bar{k}\bar{l}, k\bar{h}l\}$

201. Pinacoids. The pinacoids are the orthopinacoid, clinopinacoid and the base plane.

The *orthopinacoid* $\{100\}$ includes the two faces parallel to the plane of the bc -axis b and the vertical axis c . They have the indices 100 and $\bar{1}00$. This form is designated by the letter a , since it is situated at the extremity of the a -axis; it is hence conventionally called the a -face or a -pinacoid.

The *clinopinacoid* $\{010\}$ includes the two faces parallel to the plane of symmetry, that is the plane of the ab -axis a and the axis c . They have the indices 010 and $0\bar{1}0$. The clinopinacoid is designated by the letter b and is called the b -face or b -pinacoid.

The *base* or *basal* pinacoid $\{001\}$ includes the two terminal faces above and below, parallel to the plane of the axes a and b . They have the indices 001 and $00\bar{1}$. The base is designated by the letter c and is often called the c -face or c -pinacoid. It is conventionally marked as the orthopinacoid with the normal angle between the two faces $\{100\}$ and $\{001\}$ with the angle γ .

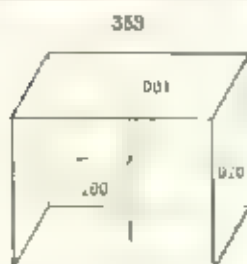
The *orthorhombic prism* forms in this class have parallel sides (Fig. 353, Fig. 354) as the analogue of face of the orthorhombic system. It is bounded by three sets of unlike faces. It has four vertical vertical edges, two of which are parallel to the a -axis, and the remaining edges parallel to the b -axis, are of two sets. Of the eight sides, there are two sets of four each, the two axes of faces are parallel to each other, but the two axes are not parallel to each other and

202. Prisms. The prisms are of no type, the orthorhombic prism. They may be viewed as three of sets as follows: the a -set prism, bounded by the faces a and b (Fig. 361, the *orthopinacoid* $\{100\}$), where $b = k$ (Fig. 362, where $b = \bar{k}$ and $a = 100$ and $a = 010$), and the *clinopinacoid* $\{010\}$ where $a = k$ (Fig. 363, where $a = \bar{k}$ and $b = 010$). The a -set prism is the a -pinacoid, the b -set prism is the b -pinacoid, and the c -set prism is the c -pinacoid.

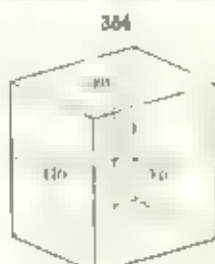
* In the present case of orthopinacoid, prism, and pinacoid, the a , b , and c are the axes of symmetry.

orthorhombic system, and the explanation on p. 140 will hence make their relation clear. Certain cases of these prisms are shown in the figures given later.

203. Orthodomes. The four faces parallel to the vertical axis b , and meeting the other two axes, fall into two sets of two each, having the general symbols $h0l$ and $\bar{h}0l$. These forms are called *orthodomes*; they are strictly hemi-orthodomes. For example, the unit *orthodome* (101) has the faces (101) and (01), but we do replace the c -axis edges between a (100) and c (001) in Fig. 353. The other unit *orthodome* ($\bar{1}01$), has the faces (01 and 101) and they would replace the c -axis edges between a (100) and c (001). These two independent forms are shown together with $h0l$ in Fig. 355.



Orthorhombic
Prism and Hemi-Orthodome



Rhombic
Prism and Orthodome



Orthodome
and Clinopinacoid

Similarly the faces 201 , $20\bar{1}$ belong to the form (201) and $\bar{2}01$, $20\bar{1}$ to the independent hemi-orthodome form (201) .

204. Clinodomes. The *clinodomes* are the forms whose faces are parallel to the inclined axis a , while intersecting the other two axes. Their general symbol is hence $0kl$ and they lie between the base (001) and the clinopinacoid (010). Each form has four faces, thus far the unit *clinodome* has the symbols, 011 , $0\bar{1}1$, $01\bar{1}$, $0\bar{1}\bar{1}$. The form $h021$ in Fig. 352 is a *clinodome*.

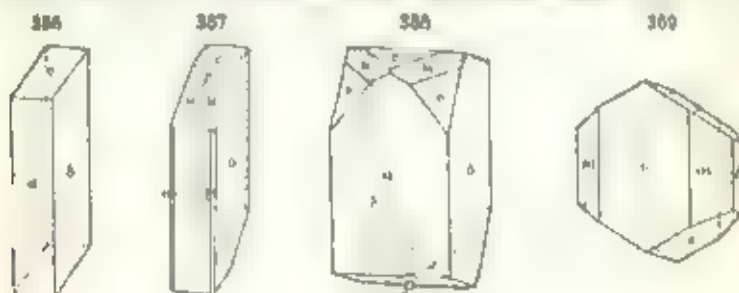
205. Pyramids. The *pyramids* in the monoclinic system are all hemi-pyramids, containing four faces only in each form, corresponding to the general symbol hkl . This obviously follows from the symmetry; it is shown for example in the fact already stated that the side angles of the unit orthoprism in Fig. 353, are above, which are replaced by these pyramids, fall into two sets of two each. Thus its general symbol, as (321) , includes the two independent forms 321 and $\bar{3}2\bar{1}$ with the faces

$$321, \quad 3\bar{2}\bar{1}, \quad \bar{3}2\bar{1}, \quad \bar{3}21 \quad \text{and} \quad 321, \quad 3\bar{2}\bar{1}, \quad \bar{3}21, \quad \bar{3}2\bar{1}$$

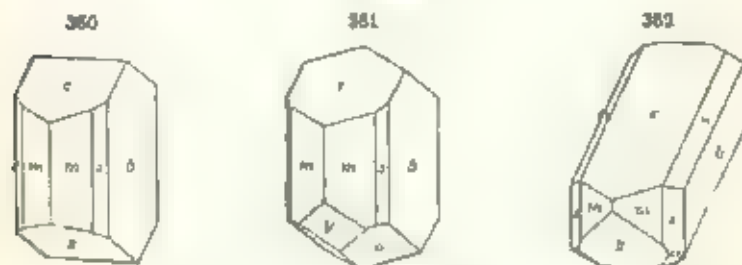
The pyramids may also be divided into three classes as *unit pyramids*, *clino-orthopyramids* hkl when $h > k$ or *orthopyramids* hkl when $h < k$. These correspond respectively to the three prisms already named. They are analogous also to the unit pyramids, macropyramids and brachypyramids of the orthorhombic system, and the explanation given on p. 141 should serve to make their relations clear. But it must be remembered that each general symbol embraces two forms (hkl and $\bar{h}\bar{k}\bar{l}$) with four faces each, as above explained.

206. Illustrations. - Figs. 354-359 of pyroxene ($a : b : c = 1.092 : 1.0 : 0.580$, $\beta = 74^\circ = \alpha(100) \wedge \alpha(001)$, show typical monoclinic forms. Fig. 359

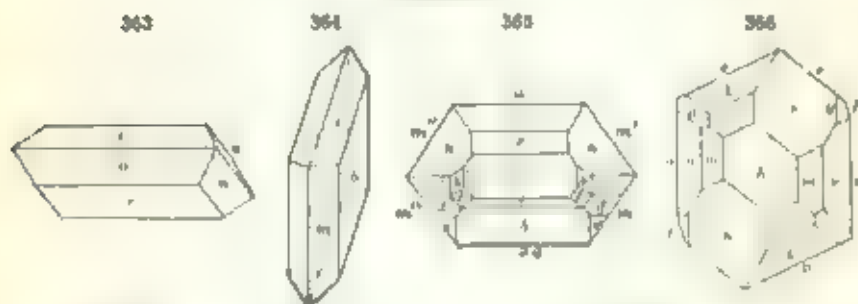
shows the diametral prism. Of the other forms, m is the unit prism (110); p (01) is an orthodome; a (11), c (22) & $\bar{1}$ (11) are pyramids, for other figures see p. 556. Again, Figs. 360-362 represent common crystals of orthoclase ($a:b:c = 0.650:1:0.557$, $\beta = 91^\circ$). Here c (10) is a prism, x , (10) and y , (20) are orthodomes, n (02) is a clinodome, o (11), a pyramid. Since (Fig. 360) c and x happen to make nearly equal angles with the vertical



Pyroxene



Orthoclase



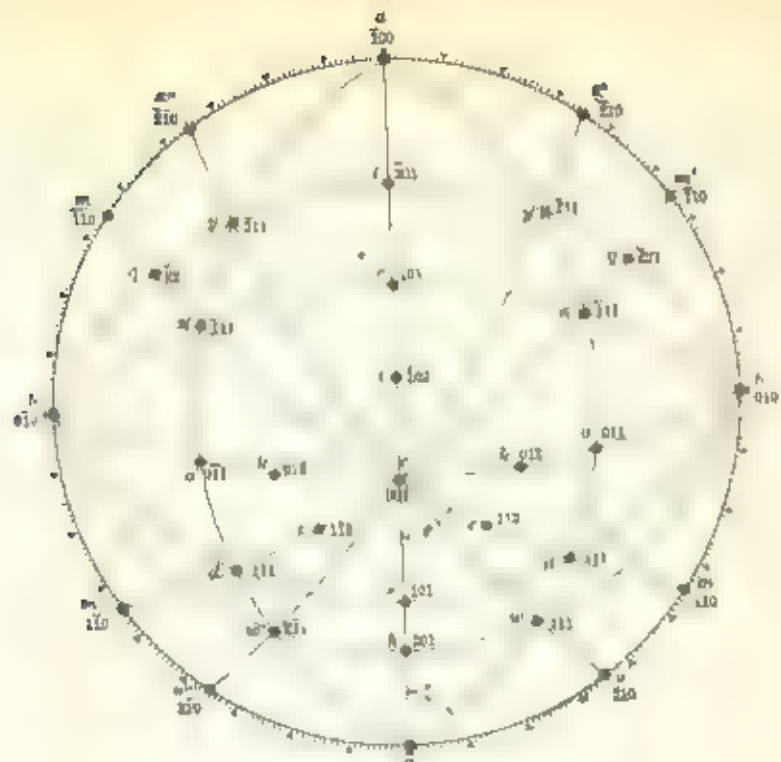
Epidote

Gypsum

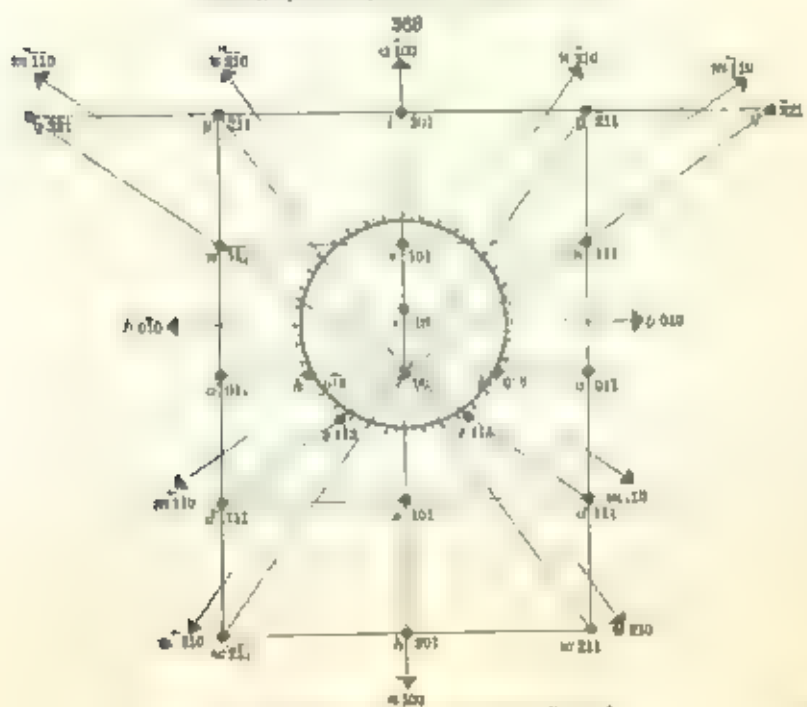
Epidote

edge of the prism m , the combination often simulates an orthorhombic crystal.

Fig. 363 shows a monoclinic crystal, epidote, prismatic in the direction of the c -axis. The forms are a (100), c (001), r (01) and s (11). Fig. 364 of gypsum is flattened $\bar{1}$ (010); it shows the unit pyramid l , (11) with the unit prism m , (10).



Stereographic Projection of Epidote Crystal



Gnomonic Projection of Epidote Crystal

207. Projections. Fig. 363 shows a projection of a crystal of epidote of Fig. 936 p. 524 on a plane normal to the prismatic zone and Fig. 366 is a similar crystal on a plane parallel to $b(010)$. Fig. 364 should be carefully studied as both the stereographic and gnomonic projections of the same species (Figs. 367-368). The symbols of the prominent faces are given in the latter figure.

2. HEMIMORPHIC CLASS 29 TARTARIC ACID TYPE

(Sphenoidal or Diagonal Polar Class)

208. b xl Ax-2. — The *monosymmetric-hemimorphic* class is characterized by a single axis of binary symmetry, the crystallographic axis $b(010)$ has no plane of symmetry. It is illustrated by the stereographic projection (Fig. 369) made upon a plane parallel to $b(010)$. Fig. 370 shows a common form of tartaric acid.



Symmetry of Hemimorphic Class



Tartaric Acid

of tartaric acid sugar crystals also belong here. The hemimorphic character is distinctly shown in the distribution of the enantiomorphs and pyramids corresponding to this the artificial salts belonging here often exhibit marked pyrametrical phenomena.

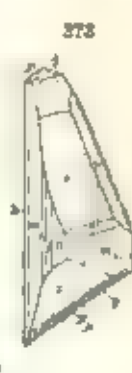
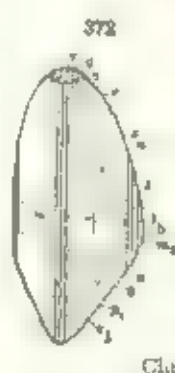
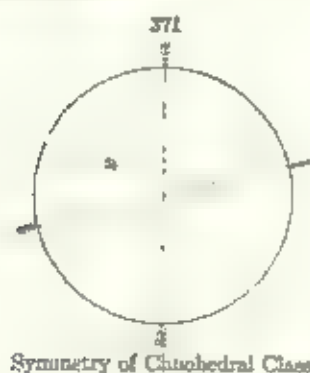
3. CLINOEDRAL CLASS 30 CLINOEDRITE TYPE

(Domestic, Hemihedral, or Planar Class)

209. a c xl P. — The *monosymmetric-clinoedral* class is characterized by a single plane of symmetry parallel to the clinopinacoid $b(010)$, and it has no axis of symmetry. This symmetry is shown in the stereographic projection made upon a plane parallel to $b(010)$ (Fig. 371). In this class, therefore, the forms parallel to the b axis, viz. (001) and (100) , and the orthopinacoids, are represented by a single face only. The other forms have each two faces, but it is to be noted that with the single exception of the clinopinacoid $b(010)$ the faces of a given form are never parallel to each other. The main given to the class is based on this fact.

Several artificial salts belong here but there are few known representatives among minerals. One is the rare silicate clinohedrite, a complex crystal of which is shown in two positions in Figs. 372, 373. As

seen in these figures, the crystals of the group have a hemimorphic aspect with respect to their development in the direction of the vertical axis, although they can not properly be called hemimorphic since this is not an axis of symmetry. The forms shown in Figs. 372-373 are as follows: pinacoid $b \perp 10$ prisms, $m \perp 10$, $m_1 \perp 10$, $h \perp 20$, $u \perp (120 \wedge 130)$, orthodome, $r \perp 10$, $e \perp 10$, pyramids, $p \perp 11$, $p_1 \perp 11$, $q \perp 11$, $r_1 \perp 31$, $s \perp (551)$, $t \perp (771)$, $w \perp (331)$, $x \perp (131)$, $y \perp (1\bar{1}1)$.



MATHEMATICAL RELATIONS OF THE MONOCLINIC SYSTEM

310. Choice of Axes. — It is repeated here (Art. 199) that the fixed position of the plane of symmetry is established by the direction of the axis of the crystal. The axes are chosen so that the axis of symmetry is the b axis and lies at right angles to the a and c axes. The a and c axes, however, may have varying positions in the vertical plane according to which axes are taken as the pinacoids $a \perp 100$ and $c \perp 001$, and which the unit pyramid prism, or axes.

311. Axial and Angular Elements. — The axial elements are the lengths of the axes a , b , and c in terms of the unit b axis, that is, the axial ratio, while the angular elements are the angles of inclination of the axes a and c , called β . Thus, for orthoclase the axial elements are

$$a : b : c = 0.535 : 1 : 0.556 \quad \beta = 83^\circ 53'$$

The angular elements are usually taken as the angle $001 \wedge 100$ which is equal to the angle a or the angles between the three planes 100 , 010 , 001 respectively, and the $m \perp 10$, the $p \perp 11$ orthodome, $0 \perp 101$ and the unit clinohedrite 011 . Thus, again for orthoclase, the angular elements are

$$\begin{aligned} 001 \wedge 100 &= 63^\circ 53', \quad 100 \wedge 110 = 30^\circ 38', \\ 001 \wedge 10 &= 50^\circ 18', \quad 001 \wedge 111 = 25^\circ 31' \end{aligned}$$

312. The mathematical relations connecting axial and angular elements are given in the following equations in which a , b , and c represent the a , b , and c lengths of the respective crystallographic axes.

$$a = \frac{\tan (100 \wedge 110)}{\sin \beta} \quad \text{or} \quad \tan (100 \wedge 110) = a \sin \beta \quad (1)$$

$$c = \frac{\tan (001 \wedge 011)}{\sin \beta} \quad \text{or} \quad \tan (001 \wedge 011) = c \sin \beta \quad (2)$$

$$\begin{aligned} c &= \frac{a \tan (001 \wedge 011)}{\sin \beta} = \frac{a \tan (001 \wedge 101)}{\sin \beta} \quad \text{or} \quad \tan (001 \wedge 101) = \frac{c \sin \beta}{a} \\ a &= \frac{c \tan (001 \wedge 101)}{\sin \beta} = \frac{c \tan (001 \wedge 111)}{\sin \beta} \quad \text{or} \quad \tan (001 \wedge 111) = \frac{a \sin \beta}{c} \end{aligned} \quad (3)$$

These relations may be made more general by writing in the several cases

$$\text{in 1. } \frac{k}{h} \text{ for } \frac{110}{100} \text{ and } \frac{k}{h} \text{ for } \frac{101}{100} \quad \text{in 2. } \frac{k}{h} \text{ for } \frac{011}{001} \text{ and } \frac{k}{h} \text{ for } \frac{101}{001}$$

$$\text{in (3) } \frac{k}{h} \text{ for } \frac{101}{100} \text{ and } \frac{k}{h} \text{ for } \frac{110}{100}$$

Also

$$\frac{c}{a} = \frac{\sin (001 \wedge 101)}{\sin (100 \wedge 101)} = \frac{\sin (001 \wedge 101)}{\sin (100 \wedge 101)}$$

and more generally

$$\frac{c}{a} = \frac{\sin (001 \wedge 101)}{\sin (100 \wedge 101)} = \frac{\sin (001 \wedge 101)}{\sin (100 \wedge 101)}$$

Note also that

$$\tan \phi = \frac{c}{a} \quad \text{and} \quad \tan \psi = \frac{c}{b},$$

where ϕ is the angle \angle of $54^\circ 44'$ between the zone-circle $001, 110$ and $001, 101$ also ψ is the angle between $001, 110$ and $001, 101$.

As to the zone-circle $001, 110$ and $001, 101$ see the preceding article.

213. In particular with $001, 110$ and $001, 101$ as zone-circle the angle between the zone-circle $001, 110$ and $001, 101$ is the angle between the zone-circle $001, 110$ and $001, 101$ from these two zone-circles of the zone-circle $001, 110$ and $001, 101$ is the angle between the zone-circle $001, 110$ and $001, 101$ from these two zone-circles of the zone-circle $001, 110$ and $001, 101$.

214. Tangent and Cotangent Relations. The tangent relation but is good for all zone-circles and for all zone-circles. The tangent relation but is good for all zone-circles and for all zone-circles. The tangent relation but is good for all zone-circles and for all zone-circles.

215. Tangent and Cotangent Relations. The tangent relation but is good for all zone-circles and for all zone-circles. The tangent relation but is good for all zone-circles and for all zone-circles. The tangent relation but is good for all zone-circles and for all zone-circles.

216. Tangent and Cotangent Relations. The tangent relation but is good for all zone-circles and for all zone-circles. The tangent relation but is good for all zone-circles and for all zone-circles. The tangent relation but is good for all zone-circles and for all zone-circles.

$$\tan (001 \wedge 101) = \frac{k}{h} \quad \text{or} \quad \tan (001 \wedge 110) = \frac{k}{h}$$

As for the zone-circle $001, 110$ and $001, 101$ see the preceding article. The zone-circle $001, 110$ and $001, 101$ is the angle between the zone-circle $001, 110$ and $001, 101$ from these two zone-circles of the zone-circle $001, 110$ and $001, 101$.

217. Tangent and Cotangent Relations. The tangent relation but is good for all zone-circles and for all zone-circles. The tangent relation but is good for all zone-circles and for all zone-circles. The tangent relation but is good for all zone-circles and for all zone-circles.

218. Tangent and Cotangent Relations. The tangent relation but is good for all zone-circles and for all zone-circles. The tangent relation but is good for all zone-circles and for all zone-circles. The tangent relation but is good for all zone-circles and for all zone-circles.

219.

$$\begin{aligned} \text{Let } 001 \wedge 101 &= PQ & \text{and} & & 001 \wedge 110 &= PR, \\ \text{or } 001 \wedge 111 &= PQ & & & 001 \wedge 110 &= PR, \\ \text{or } 001 \wedge 112 &= PQ & & & 001 \wedge 110 &= PR, \text{ etc.} \end{aligned}$$

Then for zone-circle $001, 110$ and $001, 101$ the angle \angle of $54^\circ 44'$ between the zone-circle $001, 110$ and $001, 101$ is the angle between the zone-circle $001, 110$ and $001, 101$ from these two zone-circles of the zone-circle $001, 110$ and $001, 101$.

$$\tan PQ = \frac{c}{a} \quad \text{or} \quad \tan PR = \frac{c}{b}$$

* The general formula from which the zone-circle $001, 110$ and $001, 101$ is the angle between the zone-circle $001, 110$ and $001, 101$ from these two zone-circles of the zone-circle $001, 110$ and $001, 101$.

For the corresponding zones from 001 to $\bar{1}00$ to $\bar{2}10$, etc. the expression has the same value, but here

$$PQ = 001 \wedge \bar{1}01, \quad PR = 001 \wedge \bar{1}00, \quad PS = 001 \wedge hkl, \\ \text{or} \quad 001 \wedge \bar{1}11, \text{ etc.}, \quad 100 \wedge \bar{1}10, \text{ etc.}, \quad 001 \wedge hkl, \text{ etc.}$$

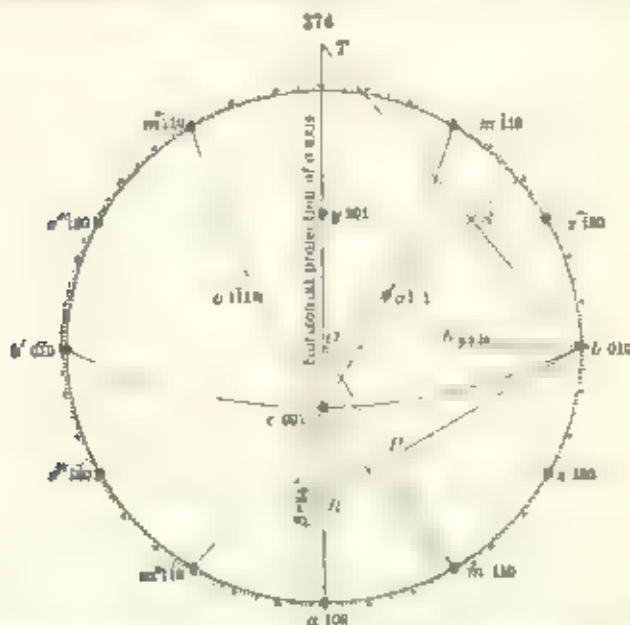
If, however, 100 is the starting-point, and

$$100 \wedge 101 = PQ, \quad 100 \wedge 001 = PR, \\ \text{or } 100 \wedge 111 = PQ, \quad 100 \wedge 011 = PR, \text{ etc.},$$

then the relation becomes

$$\frac{\cos PA}{\cos PQ} = \frac{\cos PR}{\cos PR} = 1$$

214. To determine, by plotting, the axial elements of a monoclinic crystal, given the stereographic projection of its forms. As an example of this procedure is used here that of orthoclase crystals similar to the one shown in Fig. 374 has been measured and the poles



Determination of Axial Elements of Orthoclase from Stereographic Projection

of its faces located on the stereographic projection, Fig. 374. The inclination of the a axis of the crystal is given here as 15 measured by use of the stereographic projector. The angular distance between the pole of $c 001$ and $a 100$ is 48°. In this projection the $a 100$ form does not actually occur in the crystal, it is measured as 64°. In the case of a not perfect crystal it will be possible usually to locate its position by a circle of some zone circle on which it must be. In the present case the great circle of the zone of $a 100$, $a 110$, $a 111$, $a 112$, will cross the front to back line zone of the orthoclase at the point of the pole to the base.

The ratio between the lengths of the a and b axes can be readily determined from the position of $c 001$ pole in Fig. 374. Draw the radius line OP from the center of the projection to $c 001$. From the end of the b axis draw a line at right angles to OP . This represents the intersection of the prism face with the horizontal plane and the distance OP gives the intercept of the prism upon the horizontal projection of the a axis. The distance OR

VI. TRICLINIC SYSTEM

Triclinic System

319. Crystallographic Axes. The *triclinic system* includes all the forms which are referred to three unequal axes with all their intersections. Hence

When orientated in the customary manner the axes have a vertical position and is called the *c* axis (Fig. 377), a second axis lies in the front-to-back plane sloping down, toward the observer, and is called the *a* axis. The remaining axis is designated as the *b* axis. Usually the *a* and *b* axes are so chosen that the *a* axis is the shorter axis as in the orthorhombic system is sometimes called the brachy-axis. In that case the *b* axis is longer and is known as the macro-axis.

But this is not invariably true. Thus with rhodochite the ratio of $a : b = 1.07 : 1$. The angle between the axes *b* and *c* is called α , that between *a* and *c* is β , and that between *a* and *b* is γ (Fig. 377).

Just as in the monoclinic class it is a necessary relation between the values of α , β and γ , so also they may be greater or less than 90° , this is determined by the choice of the fundamental form.

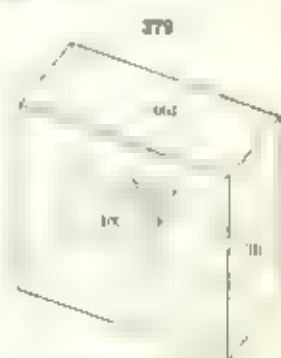
1. NORMAL CLASS (31) AXINITE TYPE

Holohedral Pinacoidal or Centric Class

220. Symmetry. *C* — The normal class of the triclinic system is characterized by a center of symmetry, the point of intersection of the three axes, but there is no plane and no axis of symmetry. The symmetry is shown in the accompanying stereographic projection (Fig. 378).



Symmetry of Normal Class



Triclinic Pinacoid

221. Forms. — Each form of the class includes two faces, parallel to one another and symmetrical with reference to the center of symmetry. This is true as well of the form with the general symbol $\{hkl\}$ as of one of the special forms, as, for example, the $\{010\}$ and $\{001\}$.

Hence, as shown in the following table, the four unit prismatic faces include two forms, namely, 110 , $\bar{1}\bar{1}0$ and $\bar{1}10$, $1\bar{1}0$. The same is true of the domes. Further, any eight corresponding pyramidal faces belong to four distinct forms, namely, 111 , $\bar{1}\bar{1}\bar{1}$, $1\bar{1}\bar{1}$, $\bar{1}11$, $\bar{1}\bar{1}1$, $11\bar{1}$, $1\bar{1}1$ and similarly in general.

The various types of forms are given in the following table:

	In notation
Macroprismal or apophanitic	$\{100\}$
Brachypyramidal or brachiprismal	$\{110\}$
Basal or epiapophanitic	$\{001\}$
Prisms	$\{010\}$ $\{0\bar{1}0\}$
Macrodomes	$\{011\}$ $\{0\bar{1}1\}$
Brachydomes	$\{111\}$ $\{1\bar{1}1\}$ $\{11\bar{1}\}$ $\{\bar{1}\bar{1}1\}$
Pyramids	$\{hkl\}$ $\{h\bar{k}l\}$ $\{hkl\}$ $\{h\bar{k}\bar{l}\}$

In the above table it is assumed that the axial ratio is such that $a < b < c$. If the opposite were true, the corresponding notation would be rearranged.

222. The explanations given under the two preceding systems make it unnecessary to discuss in detail the various forms individually, except as illustrated in the case of crystals belonging to certain typical compositions.

It may be noted, however, that Fig. 379 shows the *triclinic prism*, which is bounded by three sets of unlike faces, the prisms a , b , and c . This is the analogue of an cube of the isometric system, where the like faces, edges, and solid angles are related only to a given face, edge, and angle, and that opposite to it.

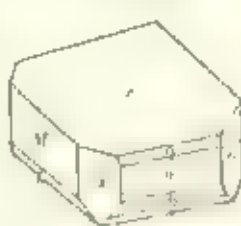
223. Illustrations. A typical orthorhombic crystal is shown in Fig. 380 of axinite. Here $a(100)$ is the macroprism, $m(110)$ and $M(110)$ the two

380



Axinite

381



Rhodanthite

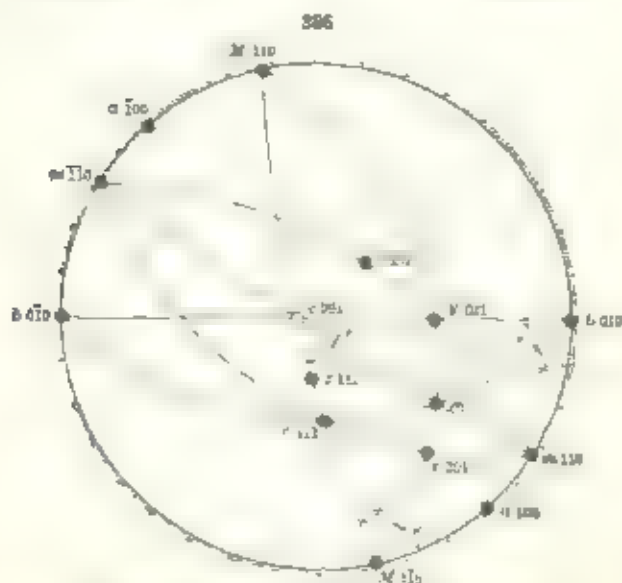
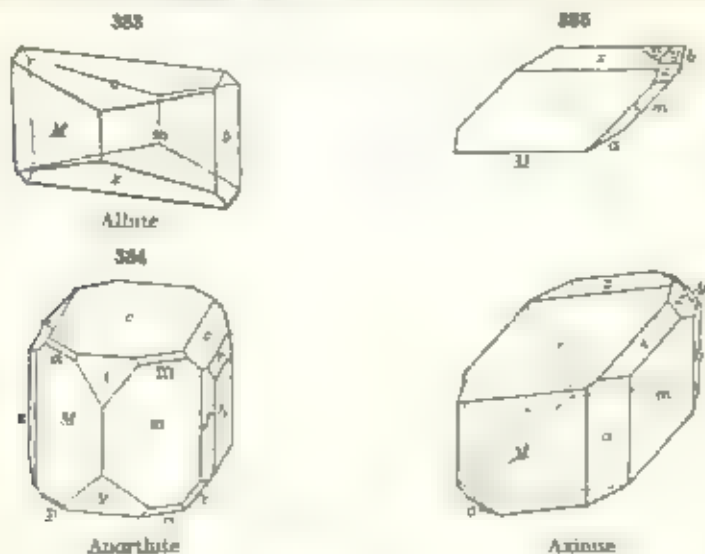
382



unit prisms $a(100)$, $c(010)$, and $b(001)$ and $m(110)$ and $M(\bar{1}\bar{1}0)$ two unit pyramids. The axial ratio is as follows:

$$a : b : c = 0.19 : 1 : 0.48 \quad \alpha = 82^\circ 54' \quad \beta = 91^\circ 52' \quad \gamma = 131^\circ 52'$$

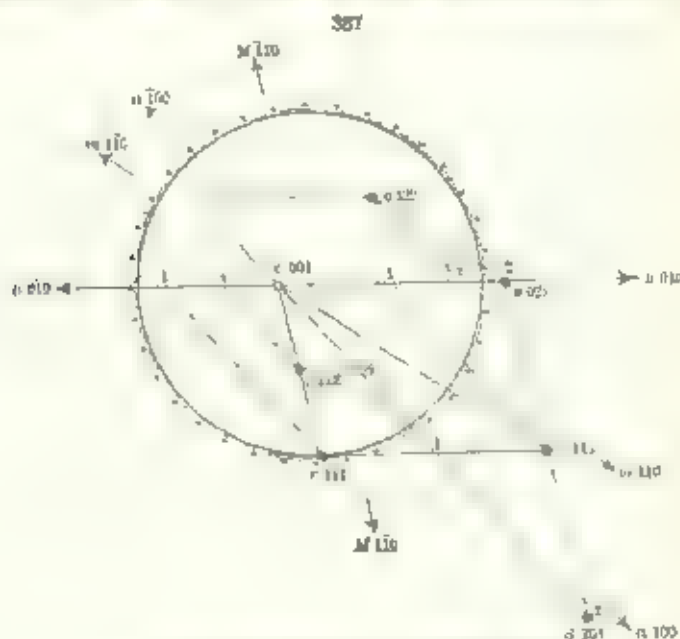
Figs 381-382 show two crystals of rhodonite, a species which is allied to pyroxene, and which approximates to it in angle and habit. Here the faces



Stereographic Projection of an Anorthite Crystal

are: P_1 faces a 100 , b 010 , c 001 prisms m 110 , M $1\bar{1}0$ pyramids a 221 , b $2\bar{2}1$, c $2\bar{1}1$, m 111 .

Further illustrations are given by Fig. 383 of albite and Fig. 384 of anorthite. The symmetries of the faces, besides the pinacoids and the unit prisms, are as follows: Fig. 383, $\pi(101)$; Fig. 384, prisms $f(130)$, $z(110)$, domes



Geometric Projection of an Axinite Crystal

$\pi(201)$, $\pi(301)$, $\pi(021)$, $\pi(031)$, $\pi(021)$ pyramids $m(111)$, $\alpha(111)$, $\pi(111)$, $\pi(111)$. In Fig. 384 (anorthite) the fact that $\pi(111)$ is one of the faces is evident on slight examination (cf. Figs. 360-361) and careful study with the measurement of angles shows that the correspondence is very close. Hence in this case the choice of the fundamental planes is readily made.

Fig. 385 represents a crystal of axinite. Figs. 386 and 387 its stereographic and geometric projections.

2. ASYMMETRIC CLASS (32) CALCIUM THIOSULPHATE TYPE

(Rhombohedral or Pedal Class)

224. No Symmetry—Besides the normal class of the triclinic system there is another possible class, possessing symmetry neither with respect to a plane, axis nor center, and if a given form has *one face only*. This class finds examples among a number of artificial salts. One of these is calcium thiosulphate ($\text{CaSO}_3 \cdot 6\text{H}_2\text{O}$), as yet no

mineral species is known to be included here. This is the most general of all the thirty-two types of crystals classified according to their symmetry and comes last, therefore, if the classes are arranged in order according to the order of symmetry characterizing them. It is a case of one of those whose crystals may show unusual adaptation. One of the eleven of the classes which have been described in the preceding pages.

MATHEMATICAL RELATIONS OF THE TRICLINIC SYSTEM

225 Choice of Axes. It is a question of great importance as to the symmetry of the system, but, as there is no such thing as a perfect crystal, the question of the choice of axes is a matter of convenience. The axes are chosen so that the three principal axes of symmetry which further fix the system are in the axes.

When the crystal is placed in a position of convenience, the three axes of the system are chosen so that the three principal axes of symmetry which further fix the system are in the axes. The three principal axes of symmetry which further fix the system are chosen so that the three principal axes of symmetry which further fix the system are in the axes.

In these cases, when the three principal axes of symmetry which further fix the system are in the axes, the three principal axes of symmetry which further fix the system are in the axes. The three principal axes of symmetry which further fix the system are in the axes.

226 Axial and Angular Elements. The axial elements of a triclinic crystal are (1) the lengths of the three principal axes, (2) the angles between the three principal axes, and (3) the angles between the three principal axes. There are three principal axes, and the angles between them are the axial elements.

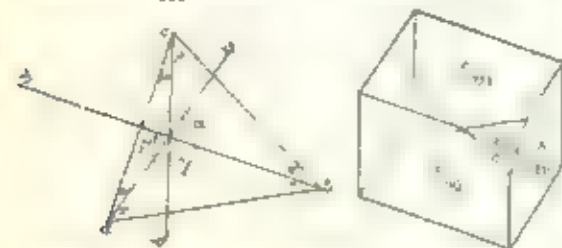
The angular elements are (1) the angles between the three principal axes, (2) the angles between the three principal axes, and (3) the angles between the three principal axes. There are three principal axes, and the angles between them are the angular elements.

$$\begin{aligned} \text{also} \quad ab, 100 \wedge 010, \quad ac, 100 \wedge 001, \quad bc, 010 \wedge 001 \\ \text{and} \quad 100 \wedge 010, \quad 001 \wedge 101, \quad 001 \wedge 011; \\ \text{or, instead, any two of all of these.} \\ aW, 100 \wedge 111, \quad 001 \wedge 101, \quad 001 \wedge 011 \end{aligned}$$

Of these six angles, however, only two are determined when the other four are known.

227 The three principal axes of a triclinic crystal are not perpendicular to each other, and the angles between them are the axial elements. The three principal axes are not perpendicular to each other, and the angles between them are the axial elements.

The three principal axes are not perpendicular to each other, and the angles between them are the axial elements. The three principal axes are not perpendicular to each other, and the angles between them are the axial elements.



The three principal axes are not perpendicular to each other, and the angles between them are the axial elements. The three principal axes are not perpendicular to each other, and the angles between them are the axial elements.

For points of these have already been explained under the monoclinic system. Art. 214. The three principal axes are not perpendicular to each other, and the angles between them are the axial elements.

228 The three principal axes of a triclinic crystal are not perpendicular to each other, and the angles between them are the axial elements. The three principal axes are not perpendicular to each other, and the angles between them are the axial elements.

289. The following equations are also often useful

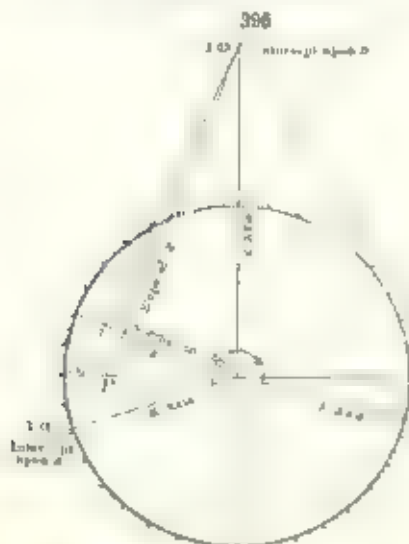
$$\begin{aligned}\tan \alpha &= \frac{2 \sin \rho \sin \rho'}{\sin(\rho - \rho')} = \frac{2 \sin \tau \sin \tau'}{\sin(\tau - \tau')} \\ \tan \beta &= \frac{2 \sin \mu \sin \mu'}{\sin(\mu - \mu')} = \frac{2 \sin(\tau + \mu) \sin \tau'}{\sin(\tau - \tau')} \\ \tan \gamma &= \frac{2 \sin \tau \sin \tau'}{\sin(\tau - \tau')} = \frac{2 \sin(\tau + \mu) \sin \mu'}{\sin(\mu - \mu')}\end{aligned}$$

4100

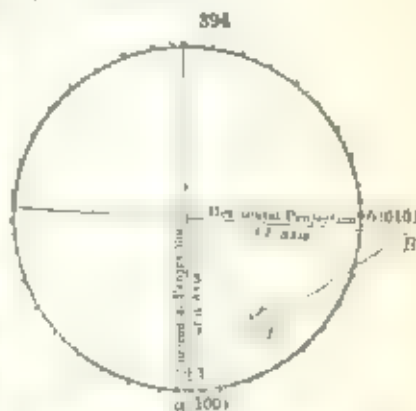
$$a + b + c = d + e + f = g + h + i = 138$$

The calculation, from the angular measurements or from the measured dimensions, is indicated by angles, either \angle of the angle or μ of the surface whose symbol is given, or \angle of the symbol of an unknown face for which measured angles are at hand (see, for an illustration, the explanation). The \angle symbol forms a \angle that is altered in a single way, as the symbol of an isosceles triangle in the comparison with the one of the square and μ of surface in addition to a symbol in the case.

230 To determine by plotting the axial elements of a triclinic crystal, having given the stereographic projection of its forms. In order to obtain the position of a crystal on a projection, we must know the position of the axes for it (forms, 100), (010), (001), (11), or be able to find the h , k , l of a crystal of any of the forms. Through these poles the great circles are drawn, as shown in the case of forms (100), (010). It appears that the angles 2θ and 2ϕ are measured as their arcs in Art. 229.



will represent the boundary or intersection of the large x with the horizon, in which the one-

[illegible]

231 To determine, by plotting, the indices of a face upon a triclinic crystal, having given the position of its pole in the stereographic projection and the axial elements of the material. To do so, this problem is possible without a face on the crystal. Its pole is located in the stereographic projection at Fig. 261. The position of the poles in Figs. 240 and 241(1) must also be known. The rectangles of the intersections of the planes of the axes and the cone of the plane of the projection can then be drawn. These give us representation of a horizontal projection of the crystal faces and axes. Suppose there are two or three axes and let the projection be circular. A circle has center O . $A_1 B_1 C_1 D_1 E_1$ are points on the circumference. $O A_1 O B_1 O C_1 O D_1 O E_1$ are radii.

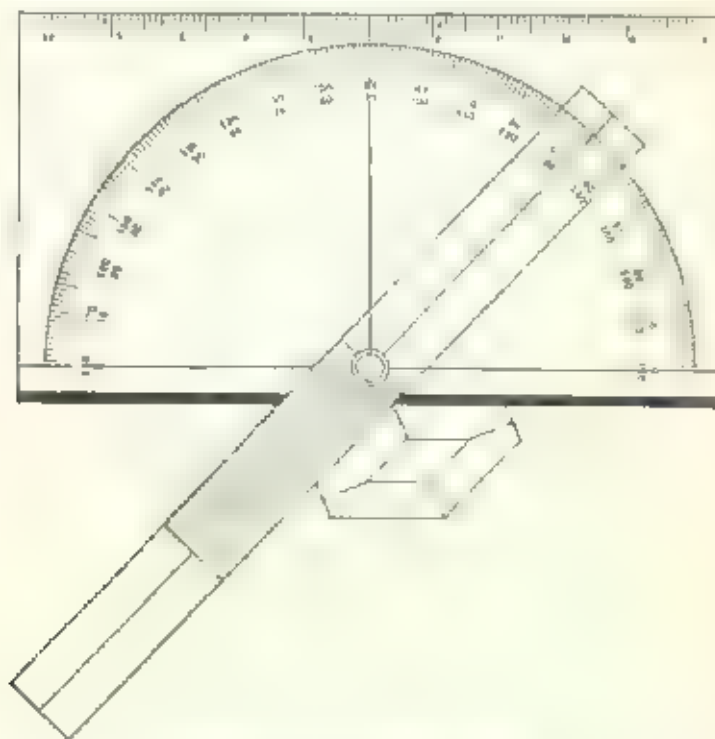
difference lies in the fact that the lines of reference upon which are plotted the intercepts of $\{hkl\}$ are drawn to them from the poles of the faces $h_1 k_1 l_1$ and $h_2 k_2 l_2$ and the angles between these reference lines are called the *zone angles* (Fig. 397). These reference lines are called also the *great circles* (Fig. 397) and the *great circles* (Fig. 397) which the angles are called *zone angles* (Fig. 397). A study of the gnomonic projection of Figure 397 will illustrate this problem.

MEASUREMENT OF THE ANGLES OF CRYSTALS

234. Contact-Goniometers. The interfacial angles of crystals are measured by means of instruments which are called *goniometers*.

The simplest form is the contact- or hand-goniometer one form of which is represented in Fig. 397.

397

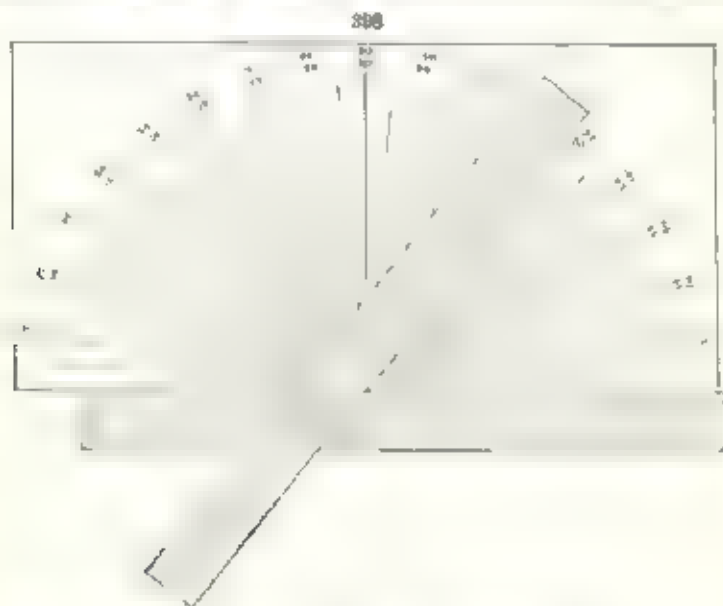


Penfield Contact Goniometer, Model B

This contact-goniometer consists of a card on which is printed a semi-circular arc graduated to half degrees at the center of which is fastened a vernier arm which may be turned to any desired position. The method of use of the goniometer is illustrated in Fig. 397. The bottom of the vernier arm and the thickened end of the vernier arm are brought to as accurate contact as possible with the two crystal faces, the angle between which is desired. Care

must be taken to see that the plane of the goniometer is at right angles to the edge of intersection between the two faces. Another model of the contact-goniometer, Fig. 308, has two arms swivelled together and separate from the graduated arc. The crystal angle is obtained by means of the arms and then the angle between them measured by placing them upon the graduated arc. This latter type is employed in cases where the crystal does not take a position as to prevent the use of the former.*

The contact-goniometer is useful in the case of large crystals and those whose faces are not well polished; the measurements with it, however, are



Penfield Contact Goniometer, Model A

seldom accurate within a quarter of a degree. In the finest specimens of crystals when the faces are smooth and distinct, results far more accurate may be obtained by means of a different instrument—namely, the reflecting goniometer.

Other more elaborate forms of contact goniometers have been designed, but it is doubtful if they can be used with any great degree of accuracy than the simple ones described above.

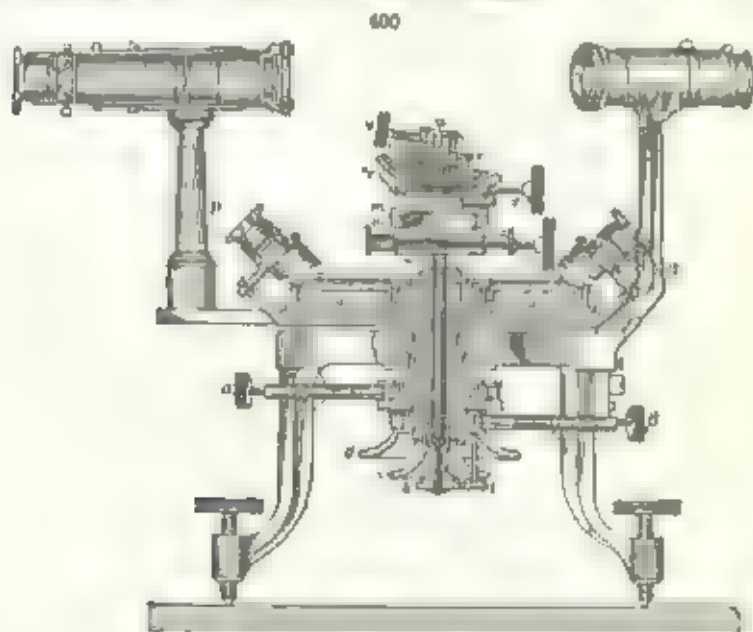
235 Reflecting Goniometer—This type of instrument was devised by Wollaston in 1801. It has undergone extensive modifications and improvements since that time. Only the perfected forms that are in common use today will be described.

The principle underlying the construction of the reflecting goniometer will be understood by reference to the figure (Fig. 309) which represents a

* These early models of contact goniometers were devised by S. J. Penfield and can be found in the collection of the Mineralogical Laboratory of the Southern Scientific School of Yale University, New Haven, Connecticut.

section of a crystal, whose angle, abc between the faces ab , bc , is required. Let the eye be placed at p and the point m be a source of light. The eye at p , looking at the face of the crystal, bc , will observe a reflected image of m , in the direction of pa . The crystal may now be so changed in its position that the same image is seen reflected by the next face and in the same direction, pa . To effect this the crystal must be turned round until abd has the present direction of bc . The angle dab measures, therefore, the number of degrees through which the crystal must be turned, it may be measured by attaching the crystal to a graduated circle which turns with the crystal. This angle is the supplement of the interior angle between the two faces, c , or rather twice at the normal angle, or angle between the two poles (see Art. 48, p. 61). The reflecting gon on c or hence gives directly the angle c used in the system of Miller here followed.

236. Horizontal Goniometer. A form of reflecting goniometer well adapted for angular measurements is shown in Fig. 300. The particular form of instrument here figured* is made by Bausch.



Two-circle Reflecting Goniometer

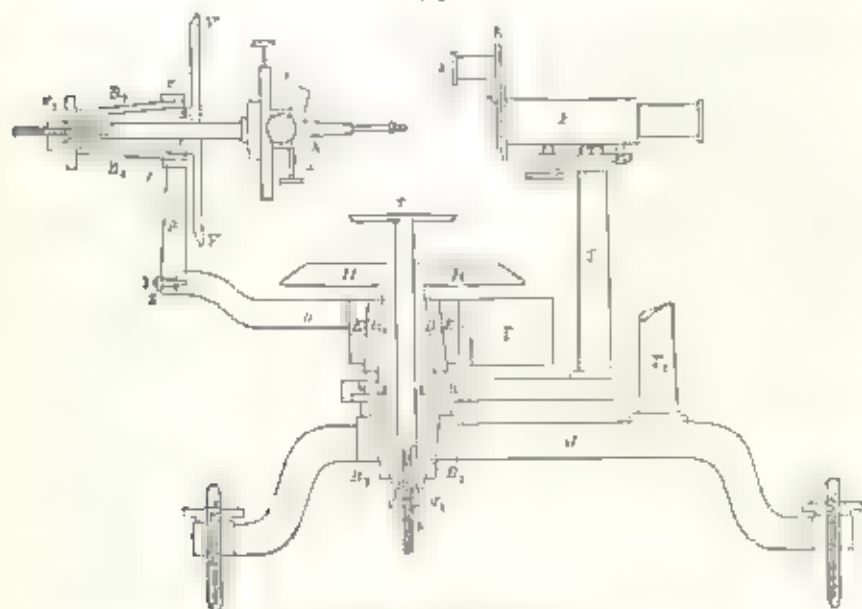
The instrument stands on a tripod with leveling screws. The central axis a has with it a hollow axis b , with which the pole c turns, carrying

* The figure here used is from the catalogue of Bausch.

the vertical circle) is equal to $010 \wedge 110$ and ρ (measured on the horizontal circle) is equal to $001 \wedge 111$.

Goldschmidt has shown that this instrument is directly applicable to the system of indices and methods of calculation and projection adopted by him, which admit the deducing of the elements and symbols of a given crystal with a minimum of labor and calculation.* Feodorow has also shown that this in-

401



Two-circle Reflector Goniometer

strument, with the addition of the appliances devised by him, can be most conveniently used in the crystallographic and optical study of crystals.

The following hints as to the methods of using this instrument may prove helpful.

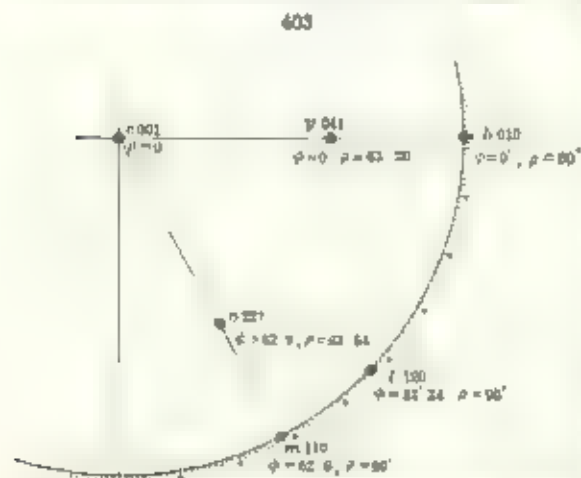
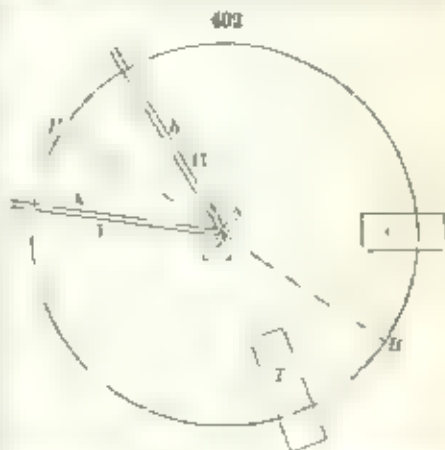
The telescope and collimator have their poles at some convenient angle to each other, usually also at 70° , and then are put in position. The next step is to find the zero position of the horizontal circle, i. e., the position at which a crystal image lying at right angles to the axis of the vertical circle will throw the collected beam of light on to the cross-hair of the telescope. Then one of the plane mirror bases or lenses must be turned to the base or of the angle between the axes of the collimator and telescope, the line AB (Fig. 402). The method by which this zero position is found is as follows. Some reflecting surface is mounted upon the end of the pole b (Fig. 401, 402), making some small fixed angle α the plane normal to that pole. Then by turning the instrument to b (the correct axis and vertical planes) this surface is brought into the proper position to reflect the signal into the telescope, see position I (Fig. 402). The true zero angle at this position is noted. Then the vertical

* See Goldschmidt's *Kristallographische Werkstätten*, 492 pp., Berlin 1897. This gives the angles required by his system for all known species. See also ZA. Krist., 20, 181, 1896. The author offers a plan for known forms. Lists of crystals in a standard work giving all previously published crystal figures together with a discussion of the forms observed upon them.

circle is turned through an angle of 180° . This swings the reflecting surface into the position represented by the dotted lines in the figure. In order to again bring the surface back to its reflecting position, the second circle with the point K as its center is moved in the horizontal plane in a like sense. It is assumed that the azimuthal remaining of this position is also noted. The angle in degrees between these two readings of the polar position observed. Thus, when the point K has a declination of the observer like P , K a plane normal to its axis will reflect a beam of light from the collimator into the telescope. The resulting result is as the zero position of the hor. zenith circle (now), which the μ angles are measured.

The method used is based on the fact that a crystal can be turned out so that it will occupy the proper position for measurement will vary with the character of the crystal. A few illustrations follow. 1. If the crystal has a basal plane at right angles to a prism zone. The crystal is mounted upon the post *h* so that the axis of the prism zone is as nearly as possible parallel to the axis of the post or the base plane as nearly as possible normal to it. Then the instrument is moved until the reading of the horizontal arc is zero and the point position is readily determined. Then by means of the timing screws the crystal is moved until the reflection from the base plane is centered upon the cross hairs of the telescope. If the adjustment has been accurately made the signal will zero and stay zero while the vertical circle is revolved. Next the horizontal circle is moved through an angle of 90°. Then watching the reflection from the face of the prism zone with the telescope. If the position of the crystal is correct the vertical circle is turned, and the reflection signal from this face falls on the horizontal cross-hair. The reading of the vertical circle and base angle is noted as when the reflection of the meridian from which the α angles are measured. If the angles β and γ are not measured

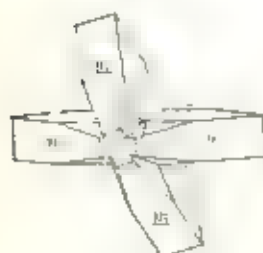
the present state of the crystal but a point of interest. Under these circumstances the hydrogen atoms in the crystal are not in a regular array from a distance of 10^{-8} cm. away from a defect, but in a regular array at a distance of 10^{-7} cm. away from a defect or impurity. The hydrogen atoms in the crystal are not in a regular array from a distance of 10^{-8} cm. away from a defect, but in a regular array at a distance of 10^{-7} cm. away from a defect or impurity. The hydrogen atoms in the crystal are not in a regular array from a distance of 10^{-8} cm. away from a defect, but in a regular array at a distance of 10^{-7} cm. away from a defect or impurity.



the jumper position and then observing reflections from these faces into the camera while reading each case. Take care to adjust the camera to bring or subtracting the angle from the polar angle of the crystal face placed in the camera in this position. Then by using the camera try to find a crystal face that all of these faces will appear very reduced the signal into the telescope as the vertical circle is turned. The operation may have to be

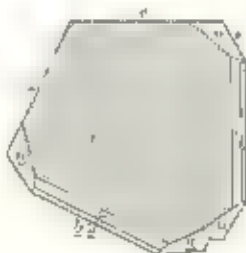
their twinned structures in the reversed arrangement of part of the faces, in the strike of the surface, and in reentrant angles, in certain cases the compound structure can only be surely detected by an examination in polarized light. The figures below (Figs. 406-408) are examples of typical kinds of twin crystals, and many others are given on the pages following.

406



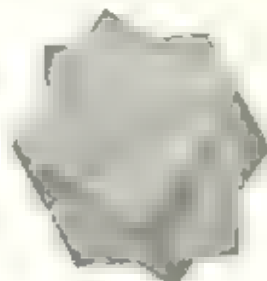
Thénardite

407



Columbite

408



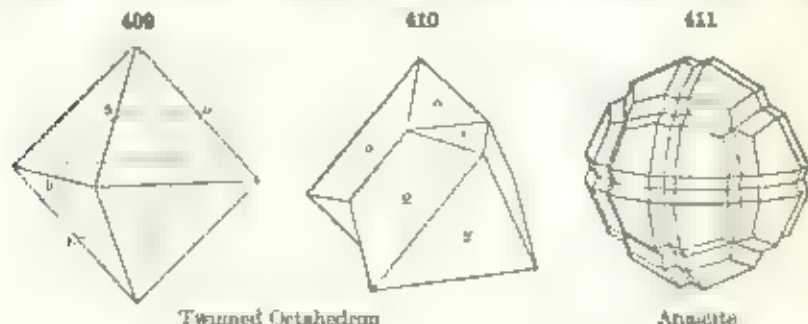
Fluorite

241. Laws of Twinning. In the majority of cases a twin crystal grows as such from the beginning. Exceptions to this rule are discussed in Arts. 243 and 244. The two (or more) individuals comprising a twin crystal have different orientations of their atomic structures, but the different positions of the crystal network must have certain places or *fixed* orientations. They must fit together in some simple way, and it must be possible to derive one orientation from another by some simple movement. Bearing in mind, therefore, that the formation of twin crystals is usually the result of a simultaneous and regular growth according to two or more crystal faces of the same atomic network, we may outline certain geometrical means of describing the results of such a compound growth.

The component parts of a twin crystal are geometrically related to each other, either as if one part was derived from the other by rotation over a plane common to both, or as if one part was derived from the other by a revolution of 180° about some crystal line common to both, or as if these two operations occurred simultaneously. The plane and axis involved in the above supposed operations are known as the *twinning-plane* and *twinning-axis*. Such twinning planes and axes have in all ordinary cases simple and rational relations to the crystal axes. In rare cases their relations to the crystal axes may not be rational, but then they have simple relations to other axes or planes which do possess such rational characters. No plane that is a symmetry plane in the individual crystal can become a twinning-plane in the compound crystal. Further, no axis of even symmetry (binary, tetragonal, or hexagonal) in the individual crystal can become a twinning-axis in the compound crystal. It is obvious if such a plane or axis were assumed as twinning-plane or axis the resulting crystal would be identical with the untwinned individual. On the other hand, a symmetry plane or axis of a class of higher symmetry may become a twinning-plane or axis of a crystal belonging in the same crystal system, but to a class of lower symmetry. Such a twin crystal may therefore assume a symmetry higher than that belonging to its components. Twin crystals of all crystal classes possessing

a center of symmetry will have both a plane of twinning and an axis of twinning normal to the plane. Where a center of symmetry is lacking a twinning-plane or axis may occur independently. These fundamental laws of twinning are illustrated in the following paragraphs.

Figs. 409 and 410 represent, respectively, a simple octahedron and its twinned form. The twinning-plane is shown in Fig. 409 by the plane, $b\bar{b}$, indicated by the broken lines, this plane being parallel to a pair of octahedron faces. In Fig. 410 is shown the twinned crystal, the faces of the front portion, which are marked o , be in positions as if they had been reflected over the twinning-plane, which, therefore, though not a symmetry plane in a simple crystal is one for the twin. The same twin can be considered as derived by a revolution on the twinning-plane of 180° about an octahedral normal. This direction, which is one of trigonal symmetry in the simple crystal, would



therefore be the twinning-axis. In this case the crystal has a center of symmetry and therefore has both a twinning-plane and -axis, normal to each other, the twinning plane is parallel to a common crystal face (111), and the twinning-axis is a simple crystallographic direction. A twinning-plane is, with rare exceptions, parallel to a possible crystal face on the given species, and usually one of the more frequent or fundamental forms. Except as to this rule occur only in the triclinic and monoclinic systems, where the twinning-axis is sometimes one of the oblique crystallographic axes and then the plane of twinning normal to it is obviously not necessarily a crystallographic plane, this is conspicuously true in the case of the pericline law of twinning in the plagioclase feldspar group (see Art. 256).

Crystals of quartz are enantiomorphous, i.e., either right- or left-handed in their development. Such crystals possess neither planes nor a center of symmetry. It is impossible to derive one type of quartz crystal from the other by any revolution about a twinning-axis, and twin crystals which combine both right and left-handed individuals therefore can possess only a plane of twinning. The Bravais law of twinning in quartz represents the case where the twin position is arrived by reflection over a twinning plane, namely, the second order prism $\{11\bar{2}0\}$ but where no twinning-axis exists. Fig. 412A shows a left-handed but quartz crystal. Fig. 412B the corresponding right-handed crystal, and Fig. 412C the combination of the two into a twinned individual, with the plane $\{11\bar{2}0\}$ indicated by the broken lines, as the twinning plane.

Fig. 434 represents a twin crystal of tetrahedrite. It is composed of two

interpenetrating tetrahedra with a normal to the tetrahedral face common to the two individuals as twinning-axis. In this case, however, there is no plane normal to the twinning-axis that could serve as a twinning-plane, i.e. as a plane over which one twin component can be derived from the other by the process of reflection.

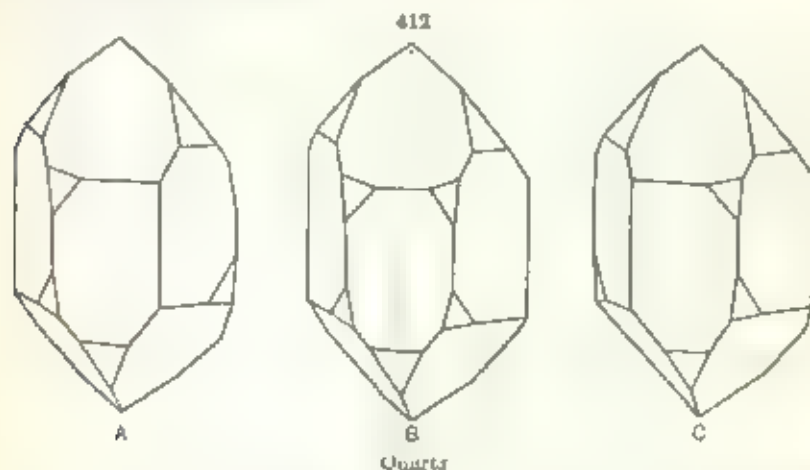
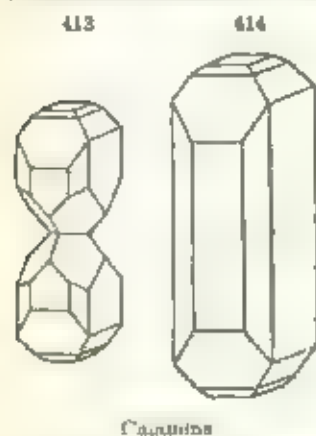


Fig. 413 represents a twin crystal of calcite. Calcite is a rhombohedral, hemimorphic. The twinning-plane here is the horizontal plane, the basal pinacoid, (001), the upper and lower halves of the twin being the reflections of each other over this plane. The vertical axis, normal to the twinning-plane, cannot be a twinning-axis since it is an axis of binary symmetry.

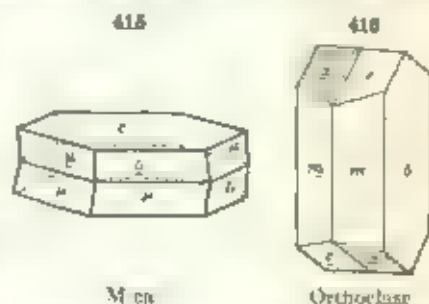


If the development of the twin crystal is such that the prisms and pinacoid faces of the two components coincide, thus eliminating the reentrant angles, the crystal will apparently possess normal orthorhombic symmetry. Such a possibility is shown in Fig. 414, where the vertical faces form composite faces joined together along the medial horizontal plane, indicated by the broken lines. Such twins, in which, owing to the twinning, all the faces are present that belong to a form of normal symmetry, are termed supplementary twins. Supplementary twins are also shown in Figs. 433-435, of pyrite, tetrahedrite and enstatite.

242. Composition-Plane. The plane by which the reversed crystals are united is the *composition-plane*. This and the twinning-plane very commonly coincide, this is true of the simple example of the twinned octahedron, described in Art. 241 and illustrated in Fig. 410. Here the plane along which the revolution may be conceived to take place (normal to the twinning-axis)

and the plane by which the semi-individuals are united are identical. When not coincident, the two planes are generally at right angles to each other—that is, the composition-plane is parallel to the axis of revolution. The normal furnishes a case in which the composition-plane of the twin crystal is at right angles to the twinning-plane. Fig. 415 represents a mica twin, the base (001) being the composition plane, the twinning-plane being the theoretical face (111) not observed on mica crystals, and the twinning-axis being a horizontal direction. Still again, where the crystals are not regularly developed, and when they interpenetrate, the contact surface may be interrupted, or may be exceedingly irregular. In such cases the axis and plane of twinning have, as always, a definite position, but the composition-plane loses its significance.

This in quartz twins the interpenetrating parts have often no regular or orderly, but haphazard in the most irregular manner throughout the mass showing this composite irregularity by abrupt variations in the character of the surfaces. This irregular internal structure, found in



many quartz crystals, even the common kinds, is well brought out by means of polarized light, and by etching with hydrofluoric acid.

The composition-plane has some times a more definite signification than the twinning-plane. This is due to the fact that in many cases, whereas the former is fixed, the twinning-axis (and twinning-plane) may be exchanged for another line and plane at right angles to each, respectively, since a revolution about the second axis will also satisfy the conditions of producing the required form. An example of this is furnished by Fig. 416, of orthoclase, the composition-plane is here fixed—namely, parallel to the crystal face, $b(010)$. But the axis of revolution may be either 1. parallel to the face $a(100)$ normal to $a(100)$ —though the axis does not coincide with the crystallographic axis c ; or 2. the twinning-axis may be taken as coinciding with the vertical axis, and then the plane normal to c is not a crystallographic face. In other simpler cases also, the same principle holds good, generally in consequence of the possible mutual interchange of the planes of twinning and composition. In most cases the true twinning plane is evident, since it is parallel to some face on the crystal of simple mathematical ratio.

343. An interesting example of the possible change between two twinning-axes at right angles to each other is furnished by the species staurolite. (Fig. 417) which is a prismatic form from Fannin Co., Georgia. The measured angle between the two twinning-axes varies from this may be taken as the face 230° which would then be the twinning-plane. Or instead of this axis, the other plane at right angles to it may be taken, which would equal well produce the observed form. Now in this species it happens that the faces 130° and 230° (over 100°), are almost exactly at right angles with each other, and, according to the latter supposition, at becomes the twinning-plane, and the axis of revolution is normal to it. Hence, either 230° or 130° may be the twinning plane, either supposition agreeing closely with the near right angle which could not be obtained with great accuracy. The former method of twinning tw. pl. 230° conforms to the other twin's observed on the species, and hence may be accepted. What is true in this case however is not always true, for it will seldom happen that of the two crystallographic axes one is nearly normal to a face of the crystal. In most cases one of the two axes conforms to the law in being a normal

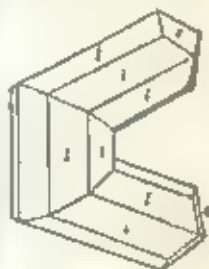
ends of the crystal are then bent into one another, and occasionally produce nearly regular prismatic forms.

This *orthogonal twinning* is sometimes presented by the successive layers of deposit on in a crystal, as in some quartz crystals, especially smoky or rose-colored ones, especially thin, being of a wavy kind. In a similar manner crystals of the triclinic feldspars, albite etc., are often made up of thin plates parallel to $h(010)$ by one lateral combination and the face $c(001)$, accordingly a finely striated parallel to the edge c/a .

246. Repeated Twinning, Polysynthetic and Symmetrical. In the preceding paragraph, one case of repeated twinning has been mentioned, that of the feldspars, it is a case of *parallel repetition* or *parallel grouping* in reverse position of successive crystalline lamellae. This kind of twinning is often called *polysynthetic twinning*, the lamellae in many cases being extremely thin, and giving rise to a series of parallel lines striations, on a crystal face or a surface of cleavage. The triclinic feldspars show in many cases polysynthetic twinning and not infrequently on both $c(001)$ and $b(010)$, cf. p. 193. It is also observed with magnetite, Topaz, pyroxene, larite etc.

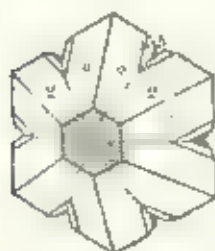
Another kind of repeated twinning is illustrated by Figs. 421–426, where the successively reversed individuals are not parallel. In these cases the axes

420



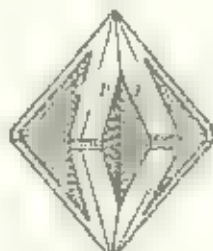
Rutile

421



Chlorophyl

422



Cerussite

423



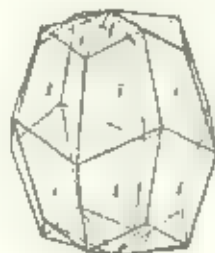
Strontolite

424



Spinel

425



Rutile

426



Phosphite

may, however, lie in a zone, as the prismatic twins of aragonite, or they may be inclined to each other as in Fig. 423 of strontolite. In all such cases the repetition of the twinning tends to produce circular forms, when the angle

between the two axial systems is an aliquot part of 360° (approximately). Thus six-rayed twinned crystals, consisting of three individuals, hence called *trilings*, occur with chrysobery (Fig. 421), or cerussite (Fig. 422), or staurolite (Fig. 423), since three times the angle of twinning in each case is not far from 360° . Again five-fold twins or *pentlings*, occur in the octahedrons of gold and silver (Fig. 424), since $5 \times 70.32 = 350^\circ$ approx. Eight-fold twins or *eightlings*, of rutile (Figs. 425, 426) occur since the angle of the axes in twinned position goes approximately eight times in 360° .

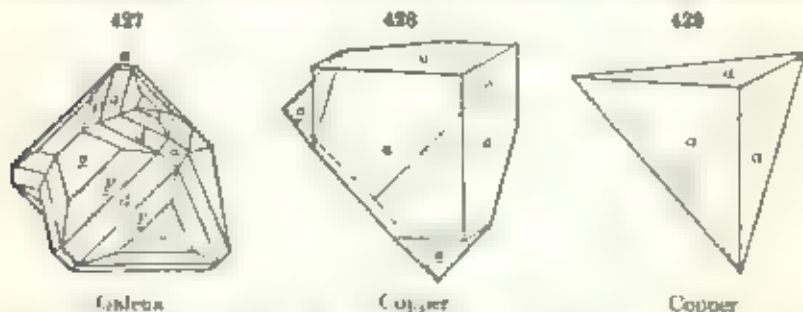
Repeated twinning of the symmetrical type often serves to give the compound crystal an apparent symmetry of higher grade than that of the single individual, and the result is of an aspect of a kind of pseudo-symmetry (Art. 20), cf. Fig. 457 of iugonite, which represents a basal section of a *pseudo-hexagonal* crystal. Fig. 426 of rutile also of Figs. 478-480 is an interesting case, since it shows how a multiple twin of a monoclinic crystal may simulate an isometric crystal (dodecahedron).

Compound crystals in which twinning exists in accordance with two laws at once are not of common occurrence. An excellent example is afforded by staurolite, Fig. 467. They have also been observed with albite, orthoclase, and in other cases.

247. Secondary Twinning.—When there is reason to believe that the twinning has been produced subsequently to the original formation of the crystal, or crystalline mass as, for example, by pressure, it is said to be *secondary*. Thus the coarse grains of a crystalline limestone often show such secondary twinning angles. The same are occasionally observed (e.g.) in pyroxene crystals. Further, the polysynthetic twinning of the triclinic feldspars is of an secondary in origin. This subject is further discussed on a later page, when it is also explained that in certain cases twinning may be produced artificially in a crystal individual—e.g., in calcite (see Art. 287).

EXAMPLES OF IMPORTANT METHODS OF TWINNING

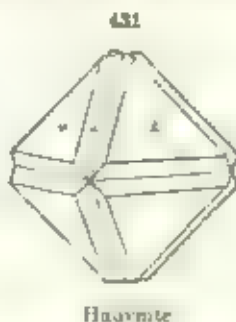
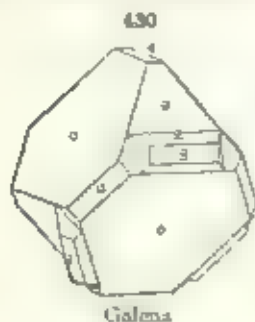
248. Isometric System. With few exceptions the twins of the normal class of this system are of one kind, the twinning-axis an octahedral axis, and



the twinning-plane consequently parallel to an octahedral face, in most cases, also, the latter coincides with the composition plane (Fig. 410, p. 181,*

* It will be noted that here and elsewhere that when used to designate the faces on the twinned parts of crystals are distinguished by a superscript π .

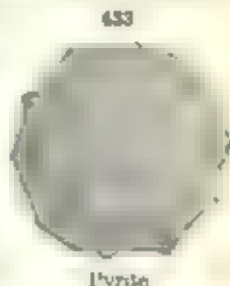
shows this kind as applied to the simple octahedron, it is especially common with the spinel group of minerals and is hence called in general a *spinel-law*. Fig. 427 is a similar more complex form. Fig. 428 shows a cube twinned by this method, and Fig. 429 represents the same form but shortened in the direction



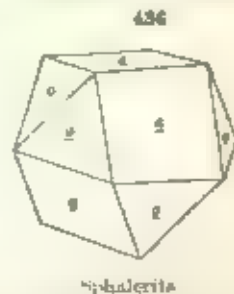
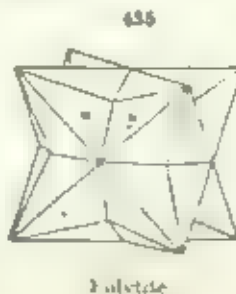
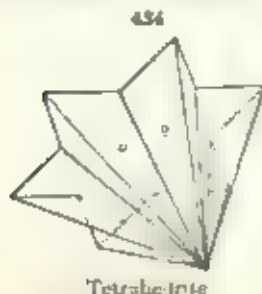
of the octahedron axis, and hence having the anomalous aspect of a triangular pyramid. All these cases are *contact-twins*.

Penetration-twins, following the same law, are also common. A simple case of fluorite is shown in Fig. 417 p. 184. Fig. 430 shows one of galena, Fig. 431 a repeated octahedral twin of hauynite, and Fig. 432 a dodecahedral twin of sodalite.

249. In the *pyritohedral* class of the isometric system penetration-twins of the type shown in Fig. 433 are common. This form of pyrite is often called the *non-cross*. Here a dodecahedral plane serves as the twinning plane and the normal to it as the twinning-axis. In this case both the plane and axis serve as symmetry elements in the normal class, and the twinned pyritohedron possesses all the planes of the normal tetrahedron. It is therefore a supplementary twin, of Art. 241.



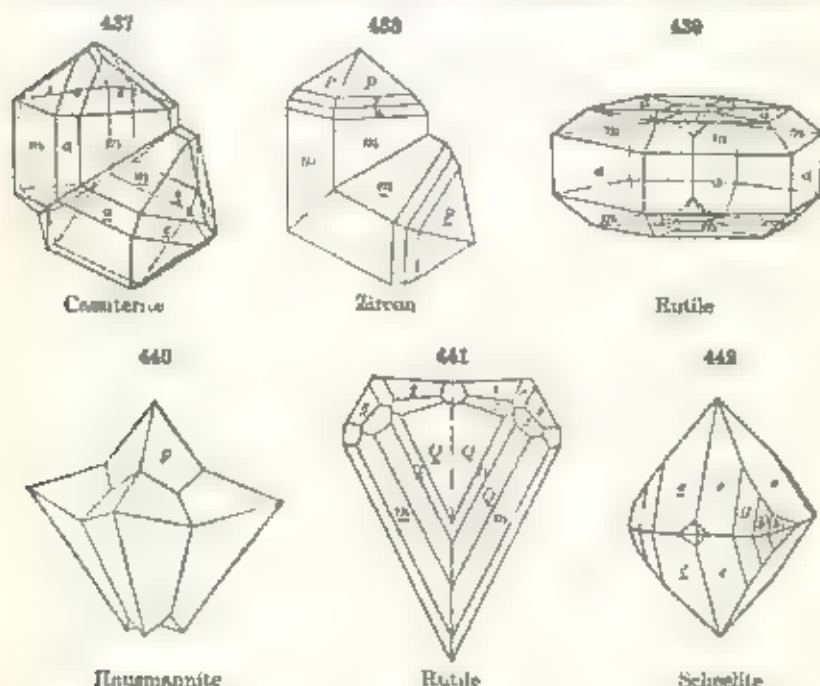
Figs. 434 and 435 show analogous forms with parallel axes for crystals belonging to the tetrahedral class. The peculiar development of Fig. 434 of



tetrahedrite is to be noted. Fig. 436 is a twin of the ordinary spiral type of another tetrahedral species, sphaerite, with it, complex forms with repeated

twinning are not uncommon and sometimes polysynthetic twin lamellae are noted.

250. Tetragonal System. The most common method is that where the twinning-plane is parallel to a face of the pyramid, $c(101)$. It is especially characteristic of the species of the rutile group—viz., rutile and cassiterite, also similarly the rarer species zircon. This is illustrated in Fig. 437, and again in Fig. 438. Fig. 439 shows a repeated twin of rutile, the twinning according to this law, the vertical axes of the successive six individuals lie in

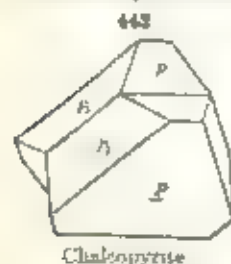


a plane (the horizontal plane of the figure), and an inclosed circle is the result. Another repeated twin of rutile is shown in Fig. 425, here the successive vertical axes form a zigzag line, e.g. 440 shows an analogous twin of hausmannite.

Another kind of twinning with the twinning-plane parallel to a face of the pyramid (301), as shown in Fig. 441.

251. In the pyramidal class of the same system twins of the type of e.g. 442 are not rare. Here the basal pinacoid is the twinning-plane, such a crystal may simulate one of the normal cases.

In chalcopyrite, of the sphenoidal class, twinning with a face of the unit sphenoid, $p(111)$, as the twinning-plane is common (Fig. 443). As the angles differ but a small fraction of a degree from those of a regular octahedron, such twins often resemble closely



spinel-twins. The face $\pi(101)$ may also be a twinning-plane and other rarer types have been noted.

252. Hexagonal System. — In the *hexagonal* division of this system twins are rare. An example is furnished by pyrrhotite, Fig. 444, where the twinning-plane is the pyramid $10\bar{1}1$, the vertical axes of the individual crystals being nearly at right angles to each other (since $\angle \text{MOI} \wedge 10\bar{1}1 = 45^\circ 8'$).

253. In the species belonging to the *trigonal* or *rhombohedral* division twins are common. Thus the twinning-axis may be the vertical axis as in the contact twins of Figs. 445 and 446, or the penetration twin of Fig. 449. Or the twinning-plane may be the *obtuse rhombohedron* $\sigma(11\bar{2})$, as in Fig. 447, the vertical axes crossing at angles of $127\frac{1}{2}^\circ$ and $52\frac{1}{2}^\circ$. Again, the twinning-plane may be $\pi(10\bar{1}1)$ as in Figs. 448-451 the vertical axes nearly at right angles ($90\frac{1}{2}^\circ$) or $\sigma(221)$, as in Fig. 452, the axes inclined $53\frac{1}{2}^\circ$ and $126\frac{1}{2}^\circ$.



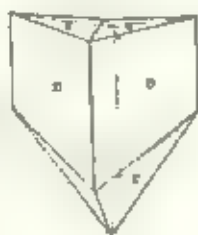
Pyrrhotite

445

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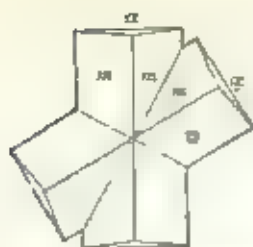
452



Figs. 445-452, Calcite

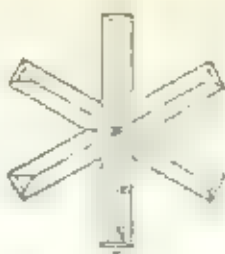
In the *trapezohedral class*, the species quartz shows several methods of twinning. In Fig. 453 the twinning-plane is the pyramid $\{11\bar{2}2\}$, the axes crossing at angles of $53\frac{1}{2}^\circ$ and $95\frac{1}{2}^\circ$. In Fig. 454 the twinning-axis is c , the axes hence parallel the individual axes both right- or both left-handed but unsymmetrical $\pi(10\bar{1}1)$ then parallel to and coinciding with $\sigma(01\bar{1})$. The resulting forms, as in Fig. 454, are mostly penetration-twins, and the parts are

458



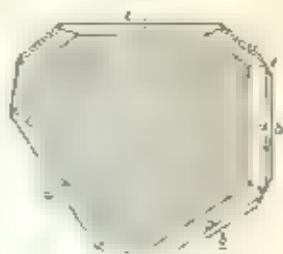
Arsenopyrite

459



Galena

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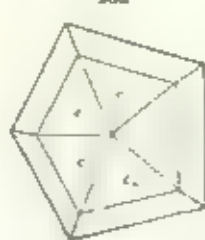


461



Marcasite

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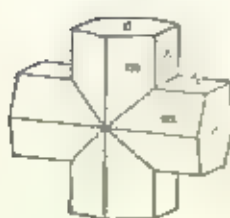
Marcasite

463



Arsenopyrite

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465



Staurolite

466



467



Staurolite

468

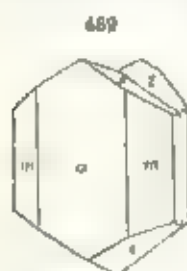


Struvite

to a face of a prism with a prism angle of about $70\frac{1}{2}^\circ$, as shown in Fig. 461. With this method symmetrical twilings not infrequently occur (Figs. 462-463).

The species *staurolite* illustrates three kinds of twinning. In Fig. 464 the twinning plane is (032), and since $001 \wedge 032 = 45^\circ 11'$, the crystals cross nearly at right angles. In Fig. 465 the twinning plane is the prism (230). In Fig. 466 it is the pyramid (232), the crystals then crossing at angles of about 60° . stellate twilings occur (see Fig. 424) and indeed more complex forms. In Fig. 467 there is twinning according to both (032) and (232).

In the hemimorphic class, twins of the type shown in Fig. 468, with $c(001)$, as the twinning plane, are to be noted.



Augite

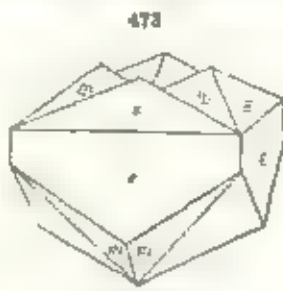


Gypsum



Orthoclase

256. Monoclinic System. — In the monoclinic system, twins with the vertical axis as twinning-axis are common (see also Art. 242, as is illustrated by Fig. 469 of augite pyroxene), Fig. 470 of gypsum, and Fig. 471 of orthoclase; see also Fig. 410, p. 183. With the latter species these twins are called *Carlsbad twins*, because common in the trachyte of Carlsbad (Bohemia), they may be contact-twins (Fig. 416), or irregular penetration-twins (Fig. 471). In Fig. 416 it is to be noted that c and x fall nearly in the same plane.

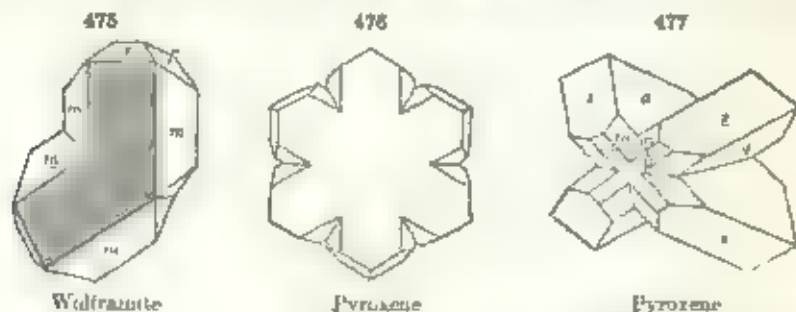


Orthoclase



In Fig. 472 also of orthoclase, the twinning plane is the clinodome (021), and since $001 \wedge 021 = 44^\circ 56'$, this line of twinning yields nearly square prisms. These twins are called *Baveno twins* (from a prominent locality, Baveno, Italy). They are often repeated (Fig. 473). In Fig. 474 a *Manchuk turn* is shown, here the twinning plane is $c(001)$. Other rarer types of twinning have been noted with orthoclase. Polysynthetic twinning with $c(001)$ as twinning plane is common with pyroxene (cf. Fig. 487, p. 195).

Twins of the aragonite-chrysoteryl type are not uncommon with monoclinic species, having a prominent 60° prism (or dome), as in Fig. 475. Stellate twins after this law are common with rhodochrosite and clinochamate. An anal ygon twin of pyroxene is shown in Fig. 476, here the pyramid (122) is the twinning-plane, and since $(010 \wedge 122) = 59^\circ 21'$, the crystals cross at angles of nearly 60° ; further, the orthopyroxene falls nearly in a common zone, since

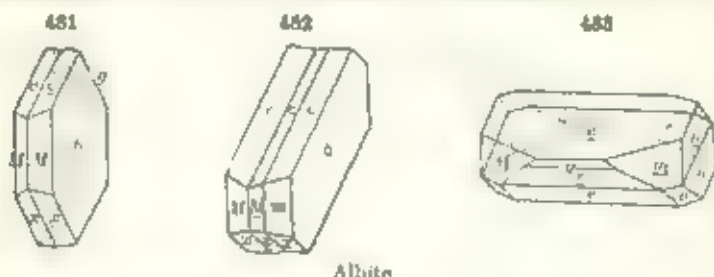


$(100 \wedge 122) = 90^\circ 9'$. In Fig. 477 the twinning-plane is the orthodome (101). Plagioclase and barroisite exhibit multiple twinning and the crystals often show pseudosymmetry. Fig. 478 shows a cruciform twinning with $c(001)$ as twinning-plane, the twinning shown by the striations on the side face. This is compounded in Fig. 479 with twinning-plane (011), making nearly square prisms, and this further repeated with $m, (110)$ as twinning plane yields the form in Fig. 480 or even Fig. 426 p. 185, resembling an isometric dodecahedron, each face showing a fourfold striation.



266. Triclinic System. The most interesting twins of the triclinic system are those shown by the feldspars. Twinning with (100) as the twinning-plane is very common, especially polysynthetic twinning yielding thin parallel lamellae, shown by the striations on the face c (or the corresponding cleavage-surface) and also clearly revealed if polarized light. This is known as the *albite law* (Figs. 481, 482). Another important method (Fig. 483) is that of the *perthite line*, the twinning-axis is the crystallographic axis b . Here the twins are united by a section, cleavage section shows, in the figure and further explained under the tetrahedron. Polysynthetic twinning

after this law is common, and hence a cleavage-mass may show two sets of striations, one on the surface parallel to $\{001\}$ and the other on that parallel to



$b(010)$. The angle made by these last striations with the edge $001/010$ is characteristic of the particular feldspar species, as noted later.

Twins of albite of other *minor* types also occur, and further twins similar to the Christad, Bavono and Manebuch twins of albite (see Fig. 484) are twinning according to both the albite and Christad types.

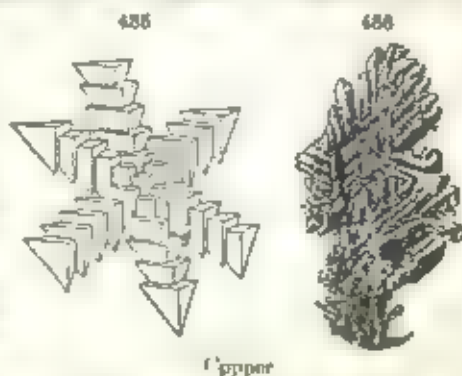
REGULAR GROUPING OF CRYSTALS

257. Parallel Grouping Connected with the subject of twin crystals is that of the parallel growth of associated crystals of the same species, or of different species.

Crystals of the same species occurring together are very commonly in parallel position. In this way large crystals, as of calcite, quartz, fluorite, are sometimes built up of

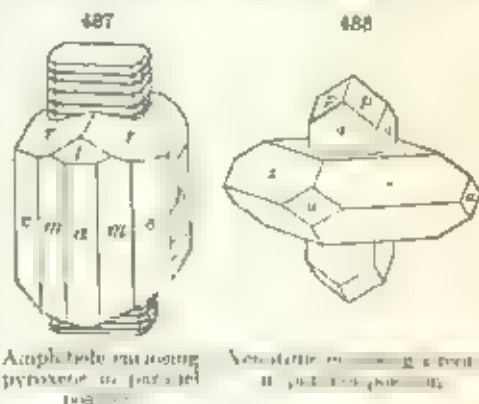
striated individuals grouped together with corresponding faces parallel. This parallel grouping is often seen in crystals as they lie on the supporting rock. On glancing over a surface covered with crystals a reflection from one face will often be accompanied by reflections from the corresponding face in each of the other crystals, showing that the crystals are throughout similar in their positions.

With many species, complex crystalline forms result from the growth of parallel partial crystals in the direction of the crystallographic axes, or axes of symmetry. These dendritic forms, resembling branching vegetation, often of great delicacy, are seen with good copper, argentite, and other species, especially those of the isometric system. This is shown in Fig. 485 (identical) and again in Fig. 486, where the twinned and flattened cubes (cf. Fig. 429, p. 186) are grouped in directions corresponding to the diagonals of an octahedral face.



258. Partial Parallel Grouping of the Same or Different Species. — Crystals of different species often show the same tendency to parallelism in mutual position. This is true most frequently of species which are more or less closely similar in form and composition. They will show a parallel position between certain usually similar planes in the two species, or the parallelism of certain directions. Such groupings of unlike species must be due to those similarities in crystal structure that control the mutual orientation of their crystals. The structural planes of the two minerals that are in contact, with each other probably have atomic arrangements and spacings of almost identical character. Crystals of calcite, implanted on surfaces of orthoclase, are sometimes an example of this; crystals of amphibole and pyroxene (Fig. 487), of zircon and xenotime (Fig. 488), of various kinds of mica, are also at times observed associated in parallel position.

The same relation of position also occasionally occurs where there is no connection in composition, as the crystals of rutile on tabular crystals of hematite, the vertical axes of the former coinciding with the horizontal axes of the latter. Crystals of calcite have been observed whose rhombohedral faces had a series of quartz crystals upon them, all in parallel position, sometimes three such quartz crystals one on each rhombohedral face, entirely envelop the calcite and unite with neighboring angles to form pseudotwins. Similar findings of quartz after crystals. Parallel growths of the spheroidal chalcopryrite upon the transverse spherulor are common, the similarity in crystal structure of the two species controlling the position of the crystals of chalcopryrite. Cases have been described of similar grouping of the crystals of the same substance in which a certain plane or direction is common to the different individuals but which the ordinary laws of twinning will not explain.



IRREGULARITIES OF CRYSTALS

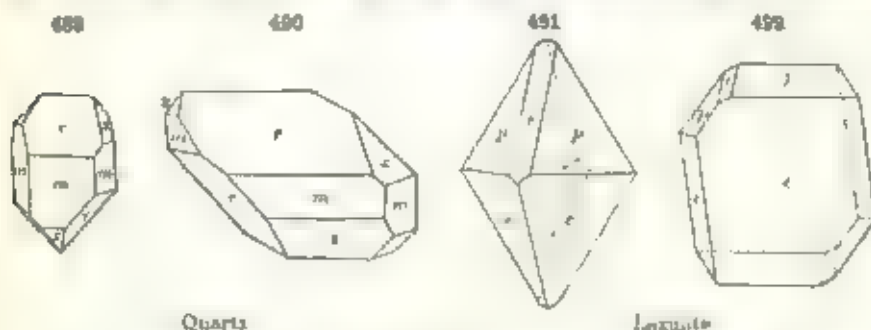
259. The laws of crystallization, when unmodified by extrinsic causes, should produce forms of exact geometrical symmetry, not only the angles being equal, but also the homogeneous faces of crystals and the dimensions in the directions of like axes. This symmetry is however so uncommon that it can hardly be considered other than an ideal perfection. The various possible kinds of symmetry, and the relation of this ideal geometrical symmetry to the actual crystallographic symmetry have been discussed in Arts. 14 and 18 of *vol. I*. Crystals are very generally distorted, and often the fundamental forms are so completely disguised that an intimate familiarity with the possible irregularities is required in order to unravel their complexities. Even the angles may occasionally vary rather widely.

The regularities of crystals may be treated under several heads: 1. *Variations of form and dimensions*; 2. *Imperfections of surface*; 3. *Variations of angles*; 4. *Internal imperfections and impurities*.

1. VARIATIONS IN THE FORMS AND DIMENSIONS OF CRYSTALS

260. Distortion in General.—The variations in the forms of crystals or in other words their *distortion*, may be *irregular* in character, certain faces being larger and others smaller than in the ideal geometrical solid. On the other hand it may be *symmetrical* giving to the distorted form the symmetry of a group or system different from that to which it actually belongs. The former case is the common rule, but the latter is the more interesting.

261. Irregular Distortion.—As stated above and on p. 13 all crystals show to a greater or less extent an irregular or accidental variation from the ideal geometrical form. This distortion, if not accompanied by change in



the interfacial angles has no particular significance, and does not involve any deviation from the laws of crystallographic symmetry. Figs. 489-490 show distorted crystals of quartz, they may be compared with the ideal form (Fig. 303, p. 130). Fig. 491 is an ideal and Fig. 492 an actual crystal of lazulite.

The correct identification of the forms on a crystal is rendered much more difficult because of this prevailing distortion, especially when it results in the *relative obliteration* of certain faces—the obliteration of others. In asphyxiated or distorted crystalline forms it is not so far from the truth to say that the preservation of the crystal may be extremely altered, the crystal angles remain the same. However, the faces are physically altered—that is, the degree of face development, and so on. Thus the prismatic faces of quartz show at once a very characteristic horizontal striations.

In addition to the variations in form which have just been described, still greater irregularities are due to the fact that in many cases crystals in nature are attached either to other crystals or to some rock surface, and in consequence of this are only partially developed. Thus quartz crystals are generally attached by one extremity of the prism, and hence have only one set of terminal faces, perfectly laminar crystals, having both ends complete are rare.

262. Symmetrical Distortion.—The most interesting examples of the symmetrical distortion of crystalline forms are found among crystals of the monoclinic system. An elongation in the direction of one of the axes may give

the appearance of tetragonal symmetry, or that in the direction of two cubic axes of orthorhombic symmetry, while in the direction of an octahedral axis a lengthening or shortening gives rise to forms of apparent rhombohedral symmetry. Such cases are common with native gold, silver, and copper.

A cube lengthened or shortened along one axis becomes a right square prism, and if varied in the direction of two axes is brought to a rectangular prism. Cubes of pyrite, galena, fluorite, etc., are often thus distorted. It is very unusual to find a cubic crystal that is a true symmetrical cube. In some species the cube or octahedron or other geometric form, as lengthened into a capillary crystal or needle, as happens in *esprits* and *pyrites*.

493



494

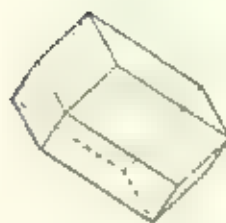


495



Distorted Octahedrons

496



497



498



499



Distorted Dodecahedrons

An octahedron flattened parallel to a face—that is, in the direction of a trigonal symmetry axis—is brought to a tabular crystal resembling a rhombohedral crystal with a basal plane (Fig. 493). If lengthened in the same direction, or along an A or B (Fig. 494), is the octahedron of the formation of rhombohedral axes, it becomes an *acute rhombohedron*.

When an octahedron is extended in the direction of a line between two opposite edges, or that of a binary symmetry axis, it has the general form of a *trigonal octahedron*, and still further extended, as in Fig. 495, it resembles a combination of two orthorhombic domes upon a common square base.

The *acute rhombohedron* lengthened in the direction of a trigonal symmetry axis becomes a *right square prism* with three-sided summits, as in Fig. 496. If shortened in the same direction, it becomes a *short prism* of the same kind (Fig. 497). Both resemble rhombohedral forms as a combination of prisms. When lengthened in the direction of one of the cubic axes, the octahedron becomes a *square prism* with pyramidal summits, as in Figs. 498 and 499. Shortened along the same axis it is reduced to a *square octahedron*, with truncated angles (Fig. 495).

The *trapezohedron* elongated in the direction of an octahedral (trigonal) axis assumes rhombohedral trigonal symmetry.

If the elongation of the trapezohedron takes place along a cubic axis, it becomes a *doubly eight-sided rhombohedron* with six-fold symmetry, or a *trigonal prism*. If planes are considered that further extend, it becomes a *trigonal eight-sided rhombohedron*.

Since the tabular or *trapezohedron* and *trigonal octahedron* may show distortion of the same kind. Further examples are to be found in the other systems.

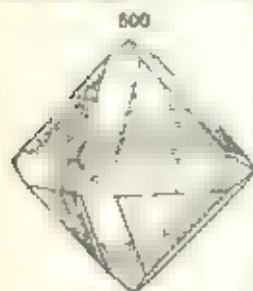
2 IMPERFECTIONS OF THE SURFACES OF CRYSTALS

263 Striations Due to Oscillatory Combinations.—The parallel lines or furrows on the surface of a crystal are called *striations* or *denudations*, and such surfaces are said to be *striated*.

Each sharp ridge on a striated surface was caused by two narrow planes more or less regular. These planes, the corresponding to position in different faces of a crystal, and these ridges have been formed by successive accretions in the operation of the causes, but give rise when cutting an interrupted, to enlarged faces. By these means, the surfaces of a crystal are marked in parallel lines with a succession of narrow planes rising at an angle and constituting the ridges referred to.

This striation on different places, the formation of a surface has been termed *oscillatory accretion*. The horizontal striations on primitive crystals of quartz are examples of this combination, in which the oscillation has taken place between the positive and the negative faces. This crystal of quartz are the most perfect point without the usual terminations.

Other examples are the striations on the cubic faces of pyrite parallel to the intersections of a cube with the faces of the parallel stream, also the striations of magnetite, the cause of friction between the combination of a dissection. Prisms of quartz are very conspicuously bounded externally by hexagonal surfaces, owing to oscillatory combination of the faces in the primitive zone.



Magnetite

264 Striations Due to Repeated Twinning. The striations on the basal plane of stibnite and other triclinic bodies, also of the rhombohedral crystals of calcite, are the result of repeated twinning. This is illustrated by the image of octahedron from Port Henry, New York (Kemp).

265 Markings from Erosion and Other Causes.

The faces of crystals are often marked and have a crystal face structure developed as a consequence of etching by some chemical agent. Crystals of garnet and feldspar, which are etched or etched in the laboratory, are marked with a level surface. Crystals of garnet and feldspar, even of other minerals, quartz, etc., sometimes show the surface result of partial change over the surface of one of the original single crystals, forming a local form, as if the whole crystal. Interesting observations have been made by various authors on the action of acid on different minerals, which have the effect of etching, and have developed in the crystals, the effect of etching is discussed, with illustrations in the article Art. 291.

The markings on the surface of crystals are not, however, always to be ascribed to etching. In many cases they represent, as well as a form, the etching upon the faces existing from the slow pyramidal growth of the processes are a part of the regular and regular growth of the crystal and often serve to show the successive stages of its history. They may be important in showing the origin of the crystal, or the process of development of a form, the perfectly smooth and regular faces being the result of completed growth free from disturbing causes. Examples of the markings referred to

occur on the crystals of most minerals, and conspicuously so on the rhombohedral faces of quartz.

Faces of crystals are often marked with angular elevations more or less distinct, which are due to oscillatory combination. Octahedrons of fluorite are common which have for each face a surface of minute cubes, proceeding from an oscillation between the cube and octahedron. Sometimes at crystallization of such a crystal shows that though the form is apparently octahedral, there are no octahedral faces present at all. Other similar cases could be mentioned.

Whatever their cause, these minute markings are often of great importance as revealing the true internal symmetry of the crystal. For it follows from the symmetry of crystallization that like faces must be physically alike—that is, in regard to their surface character. It thus often happens that on all the crystals of a species from a given locality, or perhaps from all localities, the same planes are etched or roughened alike. There is much uniformity on the faces of quartz crystals in this respect.

501



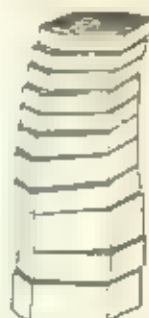
Calotte

502



Diamond

503



Berg

266. Curved surfaces may result from a) oscillatory combination; or b) some independent molecular curvature producing curvatures in the laminae of the crystal, or c) from a combined cause.

Curved surfaces of the *break kind* have been already mentioned (Art. 263). A singular example of this sort is seen in Fig. 501 of calcite. In the lower part of faces of a somewhat similar form are apparent which was in oscillatory combination with the prismatic form.

Curvatures of the *second kind* sometimes have all the faces convex. This is the case in crystals of fluorite (Fig. 502) and some of other rhombohedral spheres. The mode of curvature in which all the faces are equally convex is also common—that is, in which a convex surface is opposite and parallel to a corresponding concave surface. Rhombohedrons of dolomite and staurolite are given this curved form. The lead-ore curves of iron in windows and in flagging-stones at pavements in water are other examples. The alabaster masses from the Marathon Cave, Kentucky, are similar. Stibnite crystals sometimes show very remarkable curved and twisted forms.

A third kind of curvature is of *molecular origin*. Sometimes crystals appear as if they had been broken or reversed into many pieces, a slight displacement of which has given a curved form to the prism. This is common

in tourmaline and beryl. The beryls of Monroe, Connecticut, often present these interrupted curvatures as represented in Fig. 563.

Crystals not infrequently occur with a deep pyramidal depression occupying the place of each plane, as is often observed in common salt, alum, and sulphur. This is due in part to their rapid growth.

3. VARIATIONS IN THE ANGLES OF CRYSTALS

267. The greater part of the distortions described in Arts. 261, 262 occasion a change in the interfacial angles of crystals. But those imperfections that produce convex, concave or striated faces necessarily cause such variations. Furthermore, are instances of heat or pressure under which the crystals were formed may sometimes have resulted not only in distortion of form, but also some variation in angle. The presence of impurities at the time of crystallization may also have a like effect.

Still more important is the change in the angles of completed crystals which is caused by subsequent pressure or the matrix in which they were formed as, for example, the change which may take place during action or less complete action of heat of the enclosing rock.

The change of composition existing in gas-bourne crystals (see Art. 276) is generally accompanied by an irregular change of angle, so that the pseudomorphs of a species vary much in angle.

In general, it is difficult to affirm that, with the exception of the irregularities arising from imperfections in the process of crystallization, or from the subsequent changes caused to variations in angles are rare, and the constancy of angles noted in Art. 11 is the universal law.

In cases where a greater or less variation in angle is observed in the crystals of the same species from different localities, the cause for this can only be found in a difference of chemical composition. In the case of isomorphism compounds as we know that an exchange of corresponding equivalently equivalent elements may take place without change in color though usually accompanied with a slight variation in the fundamental angles.

The effect of heat upon the form of crystals is stated in Art. 445.

4. INTERNAL IMPERFECTIONS AND INCLUSIONS

268. The transparency of crystals is often impaired by disturbed crystallization, by imperfections taken up from the medium during the process of crystallization, or, again, by the presence of foreign matter resulting from partial chemical alteration. The general nature of inclusion is given to any foreign body included within the crystal, whatever its origin. These inclusions are extremely common, they may be gases or liquids, or solid, visible to the unaided eye or requiring the use of the microscope.

Rapid crystallization is a common explanation of inclusions. This is illustrated by quartz crystals containing large air-bubbles or empty full of water (in the latter case these showing a movable bubble) or they may contain sand or iron oxide in large amount. In the case of calcareous crystallization from a put largely charged with a foreign material as quartz sand may result in the formation of crystals in which the impurity makes up as much as two-thirds of the whole mass, as has been seen in the famous Bohemian and limestone, and similarly in that from other localities.

269. Liquid and Gas Inclusions. — Attention was early called by Brewster to the presence of fluids in cavities in certain minerals, as quartz, topaz, beryl, chrysolite, etc. In later years this subject has been thoroughly studied by Seeby, Zirkel, Vogelsang, Fischer, Rosenblazsch, and others. The nature of the liquid can often be determined by its refractive power, or by special physical tests, e.g., determination of the critical point in the case of CO_2 , or by chemical examination. In the majority of cases the observed liquid is simply water, but it may be the salt solution in which the crystal was formed, and not infrequently, especially in the case of quartz, liquid carbon dioxide (CO_2), as first proved by Vogelsang. These liquid inclusions are marked as such, in many cases by the presence in the cavity of a movable bubble of gas. Occasionally cavities contain two liquids, as water and liquid carbon dioxide, the latter then enclosing a bubble of the same substance as gas (cf. Fig. 504). Interesting experiments can be made with sections showing such inclusions (cf. literature p. 263). The mixture of gases yielded by smoky quartz, meteoric iron, and other substances, on the application of heat, has been analyzed by Wright.

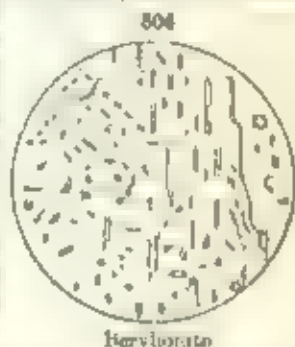
In some cases the cavities appear to be empty, if they then have a regular form determined by the crystallization of the species, they are often called *negative crystals*. Such cavities are commonly of secondary origin, as remarked on a later page.

270. Solid Inclusions. The solid inclusions are almost infinite in their variety. Sometimes they are large and distinct, and can be referred to known mineral species, as the scales of greenite or hematite to which the peculiar character of a certain feldspar is due. Magnetite is a very common impurity in many minerals, appearing, for example, in the Pennsylvanian mica; quartz is also often mechanically mixed, as in staurolite and gahnite. On the other hand, quartz crystals very commonly enclose foreign material, such as chlorite, tourmaline, rutile, hematite, arsenic, and many other minerals (cf. also Arts 271, 272).

The inclusions may consist of a heterogeneous mass of material, as the granitic matter seen in orthoclase crystals in a porphyritic granite, or the feldspar, quartz, etc., sometimes enclosed in large coarse crystals of beryl or spodumene, occurring in granite veins.

271. Microclites, Crystallites. — The microscopic crystals observed as inclusions may sometimes be referred to known species, but more generally their true nature is doubtful. The term *microclites*, proposed by Vogelsang, is often used to designate the minute included crystals; they are generally of needlelike form, sometimes quite irregular, and often very remarkable in their arrangement and groupings; some of them are exhibited in Fig. 510 and Fig. 511, as explained below. Where the minute individuals belong to known species they are called, for example, feldspar microclites, etc.

Crystallites is an analogous term used by Vogelsang to cover those minute forms which have not the regular exterior form of crystals, but may be considered as intermediate between amorphous matter and true crystals. Some of the forms are shown in Figs. 505–509; they are often observed in glassy volcanic rocks, and also in furnace-slags. A series of names has been given to



varieties of crystallites, such as glauclites, margarites, etc. Trichite and oolite are names introduced by Zirkel. The former name is derived from (p. g. *hair*) inclusions, like that in Fig. 509, are common in obsidian.



Crystallites

The intercrystalline dusts may also be of an irregular gummy nature, thus forming *intercrystalline crystals* which have formed from a broken mass, as lava or the slag of an iron furnace.

272 Symmetrically Arranged Inclusions.—In general, when the solid material is so arranged as to be irregularly in the crystals they are more properly regarded as inclusions, inasmuch as reference to the symmetry of the form, or exact faces of the crystals. A specimen of this class is shown in the following figure. Fig. 511 exhibits a crystal of magnetite, enclosing a garnet, (Fig. 512)

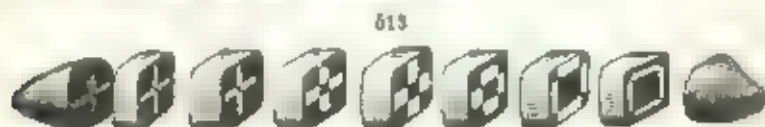


Magnetite (Zirkel)

Garnet (Zirkel)

Garnet (Zirkel) (Zirkel)

and nephrite, mercuric oxide. Fig. 511 shows a crystal of magnetite, in which the crystals are very commonly in the form of a star. Fig. 512 shows a section of a crystal of garnet containing quartz.



Anhydrite

Another striking example is furnished by anhydrite (Fig. 513), in which the small, rounded crystals are of considerable extent and remarkably arranged so as to yield symmetrical figures of various forms. Anhydrite

CRYSTALLINE AGGREGATES

273. The greater part of the specimens or masses of minerals that occur may be described as aggregations of imperfect crystals. Many specimens whose structure appears to the eye quite homogeneous and destitute internally of distinct crystallization, can be shown to be composed of crystalline grains. Under the above head, consequently, are included all the remaining varieties of structure among minerals.

The individuals composing imperfectly crystallized individuals may be

1. *Columns*, or *fibres*, in which case the structure is *columnar* or *fibrous*.
2. *Thin laminae*, producing a *lamellar* structure.
3. *Grains* constituting a *granular* structure.

274. Columnar and Fibrous Structure.—A mineral possesses a *columnar* structure when it is made up of slender columns, as some amphibole. When the individual laminae are flat-eyed like a knife-blade as in kyanite, the structure is said to be *bladed*.

The structure again is called *fibrous* when the mineral is made up of fibres, as in asbestos, also the satin-spar variety of gypsum. The fibres may or may not be separable. There are many gradations between coarse columnar and fine fibrous structures. Fibrous minerals have often a silky luster.

The following are properly varieties of columnar or fibrous structure.

Retortiated when the fibres or columns cross in various directions and produce an appearance having some resemblance to a net.

Stellated when they radiate from a center in all directions and produce star-like forms. Ex. stibite, wavellite.

Radiated, divergent when the crystals radiate from a center without producing stellar forms. Ex. quartz, stibnite.

275. Lamellar Structure.—The structure of a mineral is *lamellar* when it consists of plates or leaves. The laminae may be curved or straight, and thus give rise to the *curved lamellar* and *straight lamellar* structure. Ex. wickstonite (tubular spar), some varieties of gypsum talc etc. If the plates are approximately parallel about a common center the structure is said to be *concentric*. When the laminae are thin and separable, the structure is said to be *foliaceous* or *foliated*. Mica is a striking example and the term *micaceous* is often used to describe this kind of structure.

276. Granular Structure.—The particles in a granular structure differ much in size. When coarse, the mineral is described as *coarse-granular*; when fine, *fine-granular*, and if not distinguishable by the naked eye the structure is termed *impalpable*. Examples of the first may be observed in granular crystalline limestone, sometimes called *archaeoidal*, of the second, in some varieties of hematite of the last in some kinds of apophyllite.

The above terms are indefinite but from necessity, as there is every degree of fineness of structure among mineral species, from perfectly palpable, through all possible shades, to the coarsest granular. The term *phanero-crystalline* has been used for varieties in which the grains are distinct, and *crypto-crystalline* for those in which they are not discernible although an indistinct crystalline structure can be proved by the microscope.

Granular minerals, when easily crumbled in the fingers, are said to be *friable*.

277. Imitative Shapes.—The following are important terms used in describing the imitative forms of massive minerals.

Reniform. kidney-shaped. The structure may be radiating or concentric. Ex. hematite.

Botryoidal. consisting of a group of rounded prominences. The name is derived from the Greek *botrys*, a bunch of grapes. Ex. limonite, chalcodony, prehnite.

Mammillary. resembling the botryoidal, but composed of larger prominences. Ex. malachite.

Globular. spherical or nearly so, the globules may consist of radiating fibres or concentric coats. When attached, as they usually are, to the surface of a rock they are described as *implanted globules*.

Nodular. in tubercle form, or having irregular protuberances over the surface.

Amygdalescent. almond-shaped, applied often to a rock (as diabase) containing almond-shaped or sub-globular nodules.

Coralline. like coral, or containing of interlaced flexuous branchings of a white color, as in the variety of aragonite called *flor ferri*.

Dendritic. branching tree-like, as in crystallized gold. The term *dendrites* is used for similar forms even when not crystalline as in the dendrites of manganese oxide, which form on surfaces of limestone or are enclosed as "inclusions."

Massy. like mass in form or appearance.

Fibrous or *Capillary.* very slender and long, like a thread or hair, consists ordinarily of a succession of minute crystals. Ex. milnerite.

Acicular. slender and rigid, like a needle. Ex. stromite.

Retained art-like. See Art 274.

Dusy. closely covered with minute unplanted crystals. Ex. quartz.

Stalactite. when the mineral occurs in pendent columns, cylinders, or elongated cones. Stalactites are produced by the percolation of water, holding mineral matter in solution, through the rocky roofs of caverns. The evaporation of the water produces a deposit of the mineral matter and gradually forms a long pendent cylinder or cone. The internal structure may be imperfectly crystalline and granular, or may consist of fibres radiating from the central column, or there may be a broad cross-cleavage. The most familiar example of stalactites is afforded by calcite. Chalcodony, glibnite, limonite and some other species, also present stalactitic forms.

The term *amorphous* is used when a mineral has not only no crystalline form or imitative shape but does not polarize the light even in its minute particles and thus appears to be destitute wholly of a crystalline structure internally, as most opal. Such a structure is also called *colloidal* or *jelly-like*, from the Greek *κόλλα*, for glue. The word *amorphous* is from a primitive, and *μορφή*, shape.

278. Pseudomorphous Crystals.—Every mineral species has, when distinctly crystallized, a definite and characteristic form. Occasionally, however, crystals are found that have the form, both as to angles and general habit, of a certain species, and yet differ from it entirely in chemical composition. Moreover, it is often noted in such cases that, though in outward form complete crystals, in internal structure they are granular, or waxy, and have

no regular cleavage. Even if they are crystalline in structure the optical characters do not enable us to use resources by the symmetry of the faces.

Some minerals, however, *isomorph*, and *an isomorph* series, often by reason of their coming of direct product from the original mineral has been changed into the new compound, or it is developed through some gradual process, both direct and indirect chemical compounds which are known as *isomorph*. In these cases the new minerals are said to be a *pseudomorph* after the original mineral.

Crystals of minerals which are formed by crystals are afforded by the direct process, or by the indirect process, in the form of pyrite, barite, etc. for a full discussion of this subject is further discussed in the chapter on Chemical Mineralogy.

PART II. PHYSICAL MINERALOGY

279. The physical characters of minerals fall under the following heads:

279. The physical character of minerals may be used to identify them. The characters depending upon cleavage and fracture are: cleavage, fracture, tenacity, brittleness, etc.

[1] Specific Gravity of a Den. Li. = $\frac{\text{mass of li.}}{\text{mass of water}}$

111 Characters depending upon light via color, color intensity, transparency, special optical properties, etc.

form and of optical characters with change of temperature for bicyclic

V_1 (parameters depending upon μ and σ) and V_2 (parameters depending upon μ and σ)

VII Characters depicting upon the exterior the senses viz., taste, color, feel

280 General Relation of Physical Characters to Molecular Structure

It must not be shown. Arts 30-32 that the geometry of a crystal is not universal in the extended expression of its internal molecular structure. It is also true that the internal structure of a crystal of the same substance has a π period of its growth, and even today we see the internal structure of a crystal. All the properties of a crystal are determined by the structure of the crystal lattice, which is a periodic arrangement of atoms or ions in space. The structure of the crystal lattice is determined by the internal structure of the crystal, which is a periodic arrangement of atoms or ions in space.

all these characters the specific gravity of water gives indication of the ultimate mass of the foreign element and character of the state of molecular aggregation. The use of these points is illustrated by the high specific gravity of compounds of lead, the same as the distance is observed for example between carbon in graphite, the distance with a specific gravity of 2.5, and the same chemical substance as the mineral graphite with a specific gravity of only 2.

At the other extremes (except the red dye) are the dyes of class VI. It is generally very surprising to the chemist in the crystal color works they have a density of 1.0. For all of them, a red color is obtained which goes to the purple color for the first few physical changes.

[illegible]

It seems that people who are not as well educated as the character who is the way he thinks of getting out of a situation. He is not a very good person.

in agreement at points with the system of their rules, they do not share

all the variations in this symmetry. It is true, for example, that all directions are equally strong in a crystal belonging to any class under the isometric system, but it is a truism, in the case of its direction of cohesion, as may be shown by cleavage. Again all directions in a tetragonal crystal at right angles to the vertical axis are of the same strength, but this again is not true of the cohesion. These points are further elucidated under the description of the special characters of each group.

I. CHARACTERS DEPENDING UPON COHESION AND ELASTICITY

281. Cohesion, Elasticity. The name *cohesion* is given to the force of attraction existing between the molecules of matter in any body, in consequence of which they offer resistance to any effort tending to separate them, as in the breaking of a metal wire or a separating of two surfaces.

Plasticity is the force which enables a substance the molecules of which are taken into their original position from which they have been detached, as when a body has suffered a large degree of deformation or pressure.

The varying degrees of cohesion and elasticity for crystals of different minerals, or for different classes, as in the same crystal, are shown in the prominent characters, cleavage, fracture, tenacity, hardness, and in the gliding planes, percussion figures, or pressure figures, and in cleaving figures.

282. Cleavage. Cleavage is the tendency of a crystallized atom, to break in certain definite directions, yielding more or less smooth surfaces. It obviously indicates a minimum value of cohesion in the direction of easy fracture—that is, normal to the cleavage plane itself. The cleavage parallel to the cubic faces of a crystal of garnet is a familiar illustration. An anorthophase body, for instance, can show no cleavage.

Planes of cleavage are always planes of the crystal structure and therefore are parallel to possible crystal faces. These crystal planes have simple relations to the crystallographic axes and are usually constantly recurring forms on the crystals in question. What this is not always true is shown in the cases of triclinic and cubic, where the cleavage forms might surprise in their crystallographic relations, seldom occur as crystal forms upon their crystals. Further, cleavage is the same in all forms as in a crystal which are crystallographically identical, i.e., if a crystal exhibits parallel to one octahedral plane in an isometric substance, it will also exhibit with equal ease parallel to the three other octahedral planes. Cleavage planes have commonly been assumed to be those planes of the atomic structure in which the atoms are most closely packed together, where the distance between the successive planes is relatively large. Certain ones of this sort are undoubtedly important in determining the existence of cleavage but they cannot be the only controlling factors. For instance it has been shown that splinterite and the feldspar have identical atomic structure, but in one case the cleavage is rhombohedral and in the other octahedral. Cleavage apparently depends not only upon the geometrical position of the constituent atoms but also upon their electrical charges. The electrical forces existing between the different layers in the atomic structure are of great importance and cleavage takes place when the attractive forces are at a minimum.

Since cleavage constantly takes place parallel to some fundamental

286. Gliding-planes. Closely related to the cleavage directions in any crystalline solid, the cohesion of the molecules of a crystal are the *gliding-planes* of the atoms parallel to which a slipping of the molecules may take place under the application of mechanical force, as by pressure.

This may occur, the result of simply producing a separation into layers in the given direction, or, on the other hand, and more commonly, there may be a reposition of the molecules into a new twinning-position, so that *secondary twinning-lamellae* are formed.

Look if a crystal of quartz or rock salt be subjected to gradual pressure in the direction of a dodecahedral face a plane of separation is developed forming thus the trace of the direction of another face of the same form. There are six such directions of molecular slipping and separation in a crystal of this nature. Consider now the case of the feldspar class crystals, perthite crystals for instance, which are undoubtedly secondary in origin—that is, have been developed by pressure external and subsequent to the growth of the crystal (cf. Fig. 515).

Perthite is the form which occurs in the place of perfect cleavage, a gliding plane, the cleavage of the more easily cleaved feldspar, which is in the place of the cleavage of the more easily cleaved feldspar. A secondary twinning plane is formed in the place of the cleavage of the more easily cleaved feldspar, which is in the place of the cleavage of the more easily cleaved feldspar.

287. Secondary Twinning. The other one mentioned in the preceding article, where a new slipping, a new cleavage, a new cleavage (180°) of the molecules, a new twinning-position, set up 170 degrees, as well as in the case of the feldspar. Pressure upon a crystal of any kind may result in the formation of a new cleavage, a new twinning-position, of the parent mass, the twinning plane being held at an angle of 180 degrees, and 180 degrees. Secondary twinning, and is similar to those are often observed in natural cleavage masses of calcite and perthite in the groups of crystals, and is often observed in the groups of crystals, and is often observed in the groups of crystals.

Secondary twinning lamellae may also be produced and are often observed in nature, because of the fact that the cleavage of the feldspar is not perfect. A secondary twinning structure in quartz has been observed by J. H. Schaller, and is the result of a twinning plane of right-handed and left-handed portions.

If the proper conditions are present, a twinning plane may be produced in a crystal of quartz, and is often observed in nature, because of the fact that the cleavage of the feldspar is not perfect. A secondary twinning structure in quartz has been observed by J. H. Schaller, and is the result of a twinning plane of right-handed and left-handed portions.



Artificial Twinning in Quartz

288. Parting. The secondary twinning planes described are often directions of easy separation—commonly called *parting*—which may

a high pressure and hydrofluoric acid, the last is especially powerful in its action, and is used frequently with the silicates. The figures produced are in the majority of cases angular depressions, such as low triangular or quadrilateral pyramids whose outlines may run parallel to some of the crystalline edges. In some cases the plates produced can be referred to cleaving or crystallographic faces. More often they are of the nature of vitreous faces with complicated structure or are in fact curved surfaces. They can rarely be, however, in definite and simple crystal zones. They appear alike on similar faces of crystals, and hence serve to distinguish different forms, perhaps in appearance identical, as the two sets of faces in the ordinary double pyramid of quartz, i.e., too, they reveal the corresponding twinning-structure common on such crystals as quartz and aragonite. Further, their form in general corresponds to the symmetry of the group to which the given crystal belongs. They thus reveal the trapezohedral symmetry of quartz and the difference between right-handed and left-handed crystal. (Figs. 518-519).

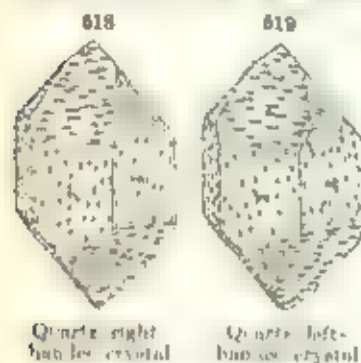


Fig. 520, the distinction between macle and doublets (Figs. 522, 523), the distinctive character of apatite, pyromorphite, etc., the hemimorphic symmetry of cymophane and nephrite (cf. Fig. 256, p. 118, etc.), they also prove by their form the monoclinic crystallization of muscovite and other minerals (Fig. 521).

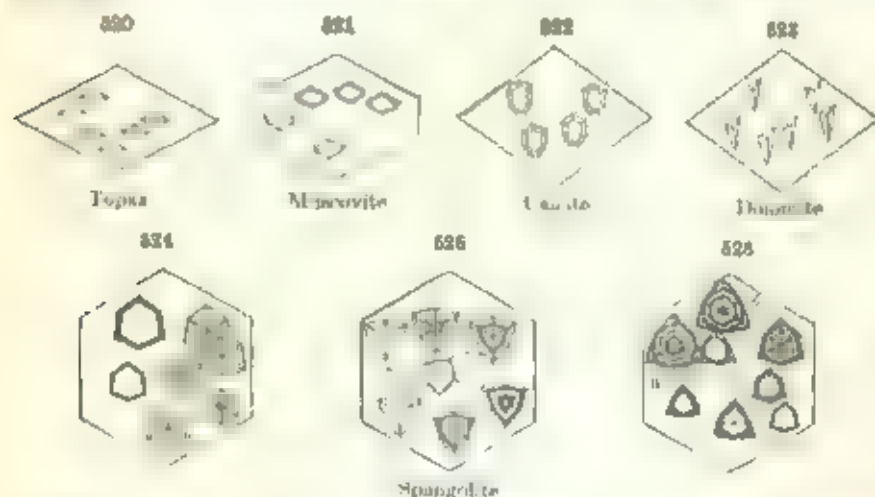


Fig. 520 shows the etching figures formed on a good plane cleavage of topaz by Fused caustic potash. (Fig. 52 shows a cleavage plate of apatite by hydrofluoric acid.) Fig. 522 is a rhombohedral face of calcite, and Fig. 523, an octahedron of dolomite by hydrofluoric acid.

The shape of the etching figures—as they vary with the same crystal with the nature of the solvent employed, the optical symmetry remains constant. For example (Fig. 524 always

the figures obtained with apophosphoric acid on a specimen of sulphuric acid. Fig. 525, by the same dater, and Fig. 526 by hydrocyanic acid of different degrees of concentration.

Of the same nature as the etching-figures artificially produced in their position to the symmetry of the crystal, are the markings often observed on the natural faces of crystals. These are sometimes secondary, caused by a natural etching process, but are more often an irregularity in the crystalline development of the crystal. The inverted triangular depressions often seen on the octahedral faces of corundum crystals are an example. Fig. 527 shows octahedral depressions, rhombohedral in character, observed on corundum crystals from Madagascar (Pratt). Fig. 528 shows a crystal of kyanite with natural etching figures. Presently these are minute pyramidal depressions whose edges are parallel to the faces of the trigonal prism (311).

292 Corrosion Forms. If the etching process spoken of in the preceding article, whether natural or artificial, is continued, the result may be very new. The original crystalline surface will disintegrate for it perhaps a new style of terraces, cavities, more or less regular, or, further, new faces may be developed, the crystallographic position of which can often be determined though the result is very complex. The mere loss of water in some cases produces certain corrosion forms.

Seefelt has prepared a sphere of quartz from a simple right-handed nucleus to the present shape of the crystal, and has found that the surface of the crystal can be etched in the various axes, but only at all at the same time.



Etched sphere of quartz

lized minerals, and in any direction in massive materials. When the cleavage is really perfect in every direction, as the rhombohedral cleavage of calcite, fracture is often not readily obtainable.

Fracture is defined as

a) *Conchoidal*—when a mineral breaks with curved concavities, more or less deep. It is so called from the resemblance of the concavity to the valve of a shell, from, *concha*, a shell. This is well illustrated by obsidian, also by

527



Corundum

528



Kyanite

Fig. 529. A sphere of quartz from a simple right-handed nucleus to the present shape of the crystal, and has found that the surface of the crystal can be etched in the various axes, but only at all at the same time.

293. Fracture. The term *fracture* is used to describe the form or kind of surface obtained by breaking in a direction other than that of cleavage in crystals.

flint. If the resulting forms are small, the fracture is said to be *small-conchoidal*, if only partially distinct it is *subconchoidal*.

b) Even, when the surface of fracture though rough with numerous small elevations and depressions, still approximates to a plane surface.

c) *Sawen* when the surface is rough and entirely irregular this is true of most minerals.

d) *Hackly* when the elevations are sharp or jagged, broken con.

Other terms also employed are *earthy*, *spidery*, etc.

294. Hardness. The *hardness* of a mineral is measured by the resistance which a smooth surface offers to abrasion. The degree of hardness is determined by observing the comparative ease or difficulty with which one mineral is scratched by another or by a file or knife.

In minerals there are all grades of hardness from that of talc, impenetrable by the finger-nail, to that of the diamond. To give precision to the use of this character, a scale of hardness was introduced by Mohs. It is as follows:

1. Talc.	6. Orthoclase.
2. Gypsum.	7. Quartz.
3. Calcite.	8. Topaz.
4. Fluorite.	9. Corundum.
5. Apatite.	10. Diamond.

Crystalline varieties with smooth surfaces should be taken so far as possible.

If a mineral under examination is scratched by the knife blade as easily as calcite its hardness is said to be 3, if less easily than calcite and more so than fluorite its hardness is 4.5. In the latter case the mineral in question would be scratched by fluorite but would not scratch calcite. It will hardly be added that great accuracy is not attainable by the above methods, though indeed, for purposes of the determination of minerals, exactness is quite unnecessary.

It should be noted that minerals of grade 1 have a greasy feel to the hand, those of grade 2 are easily scratched by the finger-nail, those of grade 3 are rather easily cut, as by a knife—of grade 4, scratch rather easily by the knife, grade 5 scratched with some difficulty, grade 6, barely scratched by a knife but readily by a file—moreover they also scratch ordinary glass. Minerals harder as quartz ($H = 7$), or harder scratch glass readily and are cut easily by a file. The few species belonging here are enumerated in Appendix H, they include all the gems.

295. Sclerometer. Accurate determinations of the hardness of minerals can be made in various ways, one of the best being by use of an instrument called a *sclerometer*. The mineral is placed in a movable carriage with the surface to be experimented upon horizontal, this is brought in contact with a steel point or a diamond point fixed on a support above, the weight is then determined which is just sufficient to move the carriage and produce a scratch on the surface of the mineral.

By means of such an instrument the hardness of the different faces of a given crystal has been determined in a variety of cases. It has been found that different faces of a crystal, e.g., kyanite differ in hardness and the same face may differ as it is scratched in different directions. The degree of ease with which a given mineral is scratched is a measure of its molecular cohesion,

and in cases where the cohesion varies with the direction it is obvious that the hardness will likewise vary. In general, differences in hardness are noted only with crystals which show distinct cleavage; the hardest face is that which is intersected by the plane of most complete cleavage. Further, of a single face which is intersected by cleavage-planes, the direction perpendicular to the cleavage-direction is the softer; those parallel to it the harder.

This subject has been investigated by Haase (p. 10), who has given the form of the curves of hardness for the different forms of many crystals. These curves are obtained as follows: The least weight required to scratch a crystalic surface in different directions, is each 10 or 5 times 0 to 100, as recommended with the microscope; these curves are laid off as in 1, from a center and the angle of each curve corresponds to the weight fixed by experiment. The angle is two-thirds that determined by the line connecting the extremities of these radii to the center of the circle for the given face.

The following table given by Roscoe (Ann. Mag. Nat. Hist., London, 1854) in comparing the hardness of the minerals of the scale from Cornwall, No. 2, taken as 1000 to gypsum, No. 2, (Haase used the standard of having a 11 as standard), the numbers being as arranged by the number of rotations; Roscoe uses a diamond powder to grade them; the larger number implies less resistance to scratch. The method being essentially a modification of that of Haase, by means of which the latter might be able to see a hardness of the crystals present in a thin section, and the microscope. Measurements of absolute hardness have since been made. As far as Haase has been concerned, many hardness tests by the grinding method. The results will be referred to in connection with the results of the hardness tests with the stone of Roscoe given before to show complete correspondence with the results obtained by the other methods. He, like Roscoe, finds that corundum is softer in the sense than quartz.

	Haase 1854	Roscoe 1892	Jaggard 1897
9. Corundum	1000	1000	1000
8. Topaz	350	100	152
7. Quartz	250	119	40
6. Orthoclase	10	24.7	26
5. Apatite	83.5	0.20	1.33
4. Fluorite	87.3	4.70	7.8
3. Calcite	15.3	2.68	20
2. Gypsum	12.05	.94	.04

290. Relation of Hardness to Chemical Composition.—Some general facts of importance can be pointed out, related to the connection between the hardness of a mineral and its chemical composition.

1. Compounds of the heavy metals, as silver, copper, mercury, lead, etc., are soft, their hardness seldom exceeding 5 or 6.

2. Among the compounds of the transition metals the sulphides, arsenides and selenides of iron, also of nickel and cobalt, are relatively soft, for example, FeS 4.85, for hardness $H = 0.07$, FeAs_2 4.00, being a soft compound, iron sulphate, barite, and tantaleum, however, are hard.

3. The sulphides are generally relatively soft, except as noted in 1, also most of the phosphates, sulphates and chlorides.

4. Hydrates are generally soft. This is most distinctly shown among the silicates—e.g., $\text{Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$ are the softest, as is also Fe_2O_3 .

5. The compounds of the transition metals are found chiefly among the oxides and sulphides, many of them are, however, as exhibited by the iron, Fe_2O_3 , Fe_3O_4 , FeS , FeAs_2 , FeS_2 , FeS_3 , FeS_4 , FeS_5 , FeS_6 , FeS_7 , FeS_8 , FeS_9 , FeS_{10} , FeS_{11} , FeS_{12} , FeS_{13} , FeS_{14} , FeS_{15} , FeS_{16} , FeS_{17} , FeS_{18} , FeS_{19} , FeS_{20} , FeS_{21} , FeS_{22} , FeS_{23} , FeS_{24} , FeS_{25} , FeS_{26} , FeS_{27} , FeS_{28} , FeS_{29} , FeS_{30} , FeS_{31} , FeS_{32} , FeS_{33} , FeS_{34} , FeS_{35} , FeS_{36} , FeS_{37} , FeS_{38} , FeS_{39} , FeS_{40} , FeS_{41} , FeS_{42} , FeS_{43} , FeS_{44} , FeS_{45} , FeS_{46} , FeS_{47} , FeS_{48} , FeS_{49} , FeS_{50} , FeS_{51} , FeS_{52} , FeS_{53} , FeS_{54} , FeS_{55} , FeS_{56} , FeS_{57} , FeS_{58} , FeS_{59} , FeS_{60} , FeS_{61} , FeS_{62} , FeS_{63} , FeS_{64} , FeS_{65} , FeS_{66} , FeS_{67} , FeS_{68} , FeS_{69} , FeS_{70} , FeS_{71} , FeS_{72} , FeS_{73} , FeS_{74} , FeS_{75} , FeS_{76} , FeS_{77} , FeS_{78} , FeS_{79} , FeS_{80} , FeS_{81} , FeS_{82} , FeS_{83} , FeS_{84} , FeS_{85} , FeS_{86} , FeS_{87} , FeS_{88} , FeS_{89} , FeS_{90} , FeS_{91} , FeS_{92} , FeS_{93} , FeS_{94} , FeS_{95} , FeS_{96} , FeS_{97} , FeS_{98} , FeS_{99} , FeS_{100} , FeS_{101} , FeS_{102} , FeS_{103} , FeS_{104} , FeS_{105} , FeS_{106} , FeS_{107} , FeS_{108} , FeS_{109} , FeS_{110} , FeS_{111} , FeS_{112} , FeS_{113} , FeS_{114} , FeS_{115} , FeS_{116} , FeS_{117} , FeS_{118} , FeS_{119} , FeS_{120} , FeS_{121} , FeS_{122} , FeS_{123} , FeS_{124} , FeS_{125} , FeS_{126} , FeS_{127} , FeS_{128} , FeS_{129} , FeS_{130} , FeS_{131} , FeS_{132} , FeS_{133} , FeS_{134} , FeS_{135} , FeS_{136} , FeS_{137} , FeS_{138} , FeS_{139} , FeS_{140} , FeS_{141} , FeS_{142} , FeS_{143} , FeS_{144} , FeS_{145} , FeS_{146} , FeS_{147} , FeS_{148} , FeS_{149} , FeS_{150} , FeS_{151} , FeS_{152} , FeS_{153} , FeS_{154} , FeS_{155} , FeS_{156} , FeS_{157} , FeS_{158} , FeS_{159} , FeS_{160} , FeS_{161} , FeS_{162} , FeS_{163} , FeS_{164} , FeS_{165} , FeS_{166} , FeS_{167} , FeS_{168} , FeS_{169} , FeS_{170} , FeS_{171} , FeS_{172} , FeS_{173} , FeS_{174} , FeS_{175} , FeS_{176} , FeS_{177} , FeS_{178} , FeS_{179} , FeS_{180} , FeS_{181} , FeS_{182} , FeS_{183} , FeS_{184} , FeS_{185} , FeS_{186} , FeS_{187} , FeS_{188} , FeS_{189} , FeS_{190} , FeS_{191} , FeS_{192} , FeS_{193} , FeS_{194} , FeS_{195} , FeS_{196} , FeS_{197} , FeS_{198} , FeS_{199} , FeS_{200} , FeS_{201} , FeS_{202} , FeS_{203} , FeS_{204} , FeS_{205} , FeS_{206} , FeS_{207} , FeS_{208} , FeS_{209} , FeS_{210} , FeS_{211} , FeS_{212} , FeS_{213} , FeS_{214} , FeS_{215} , FeS_{216} , FeS_{217} , FeS_{218} , FeS_{219} , FeS_{220} , FeS_{221} , FeS_{222} , FeS_{223} , FeS_{224} , FeS_{225} , FeS_{226} , FeS_{227} , FeS_{228} , FeS_{229} , FeS_{230} , FeS_{231} , FeS_{232} , FeS_{233} , FeS_{234} , FeS_{235} , FeS_{236} , FeS_{237} , FeS_{238} , FeS_{239} , FeS_{240} , FeS_{241} , FeS_{242} , FeS_{243} , FeS_{244} , FeS_{245} , FeS_{246} , FeS_{247} , FeS_{248} , FeS_{249} , FeS_{250} , FeS_{251} , FeS_{252} , FeS_{253} , FeS_{254} , FeS_{255} , FeS_{256} , FeS_{257} , FeS_{258} , FeS_{259} , FeS_{260} , FeS_{261} , FeS_{262} , FeS_{263} , FeS_{264} , FeS_{265} , FeS_{266} , FeS_{267} , FeS_{268} , FeS_{269} , FeS_{270} , FeS_{271} , FeS_{272} , FeS_{273} , FeS_{274} , FeS_{275} , FeS_{276} , FeS_{277} , FeS_{278} , FeS_{279} , FeS_{280} , FeS_{281} , FeS_{282} , FeS_{283} , FeS_{284} , FeS_{285} , FeS_{286} , FeS_{287} , FeS_{288} , FeS_{289} , FeS_{290} , FeS_{291} , FeS_{292} , FeS_{293} , FeS_{294} , FeS_{295} , FeS_{296} , FeS_{297} , FeS_{298} , FeS_{299} , FeS_{300} , FeS_{301} , FeS_{302} , FeS_{303} , FeS_{304} , FeS_{305} , FeS_{306} , FeS_{307} , FeS_{308} , FeS_{309} , FeS_{310} , FeS_{311} , FeS_{312} , FeS_{313} , FeS_{314} , FeS_{315} , FeS_{316} , FeS_{317} , FeS_{318} , FeS_{319} , FeS_{320} , FeS_{321} , FeS_{322} , FeS_{323} , FeS_{324} , FeS_{325} , FeS_{326} , FeS_{327} , FeS_{328} , FeS_{329} , FeS_{330} , FeS_{331} , FeS_{332} , FeS_{333} , FeS_{334} , FeS_{335} , FeS_{336} , FeS_{337} , FeS_{338} , FeS_{339} , FeS_{340} , FeS_{341} , FeS_{342} , FeS_{343} , FeS_{344} , FeS_{345} , FeS_{346} , FeS_{347} , FeS_{348} , FeS_{349} , FeS_{350} , FeS_{351} , FeS_{352} , FeS_{353} , FeS_{354} , FeS_{355} , FeS_{356} , FeS_{357} , FeS_{358} , FeS_{359} , FeS_{360} , FeS_{361} , FeS_{362} , FeS_{363} , FeS_{364} , FeS_{365} , FeS_{366} , FeS_{367} , FeS_{368} , FeS_{369} , FeS_{370} , FeS_{371} , FeS_{372} , FeS_{373} , FeS_{374} , FeS_{375} , FeS_{376} , FeS_{377} , FeS_{378} , FeS_{379} , FeS_{380} , FeS_{381} , FeS_{382} , FeS_{383} , FeS_{384} , FeS_{385} , FeS_{386} , FeS_{387} , FeS_{388} , FeS_{389} , FeS_{390} , FeS_{391} , FeS_{392} , FeS_{393} , FeS_{394} , FeS_{395} , FeS_{396} , FeS_{397} , FeS_{398} , FeS_{399} , FeS_{400} , FeS_{401} , FeS_{402} , FeS_{403} , FeS_{404} , FeS_{405} , FeS_{406} , FeS_{407} , FeS_{408} , FeS_{409} , FeS_{410} , FeS_{411} , FeS_{412} , FeS_{413} , FeS_{414} , FeS_{415} , FeS_{416} , FeS_{417} , FeS_{418} , FeS_{419} , FeS_{420} , FeS_{421} , FeS_{422} , FeS_{423} , FeS_{424} , FeS_{425} , FeS_{426} , FeS_{427} , FeS_{428} , FeS_{429} , FeS_{430} , FeS_{431} , FeS_{432} , FeS_{433} , FeS_{434} , FeS_{435} , FeS_{436} , FeS_{437} , FeS_{438} , FeS_{439} , FeS_{440} , FeS_{441} , FeS_{442} , FeS_{443} , FeS_{444} , FeS_{445} , FeS_{446} , FeS_{447} , FeS_{448} , FeS_{449} , FeS_{450} , FeS_{451} , FeS_{452} , FeS_{453} , FeS_{454} , FeS_{455} , FeS_{456} , FeS_{457} , FeS_{458} , FeS_{459} , FeS_{460} , FeS_{461} , FeS_{462} , FeS_{463} , FeS_{464} , FeS_{465} , FeS_{466} , FeS_{467} , FeS_{468} , FeS_{469} , FeS_{470} , FeS_{471} , FeS_{472} , FeS_{473} , FeS_{474} , FeS_{475} , FeS_{476} , FeS_{477} , FeS_{478} , FeS_{479} , FeS_{480} , FeS_{481} , FeS_{482} , FeS_{483} , FeS_{484} , FeS_{485} , FeS_{486} , FeS_{487} , FeS_{488} , FeS_{489} , FeS_{490} , FeS_{491} , FeS_{492} , FeS_{493} , FeS_{494} , FeS_{495} , FeS_{496} , FeS_{497} , FeS_{498} , FeS_{499} , FeS_{500} , FeS_{501} , FeS_{502} , FeS_{503} , FeS_{504} , FeS_{505} , FeS_{506} , FeS_{507} , FeS_{508} , FeS_{509} , FeS_{510} , FeS_{511} , FeS_{512} , FeS_{513} , FeS_{514} , FeS_{515} , FeS_{516} , FeS_{517} , FeS_{518} , FeS_{519} , FeS_{520} , FeS_{521} , FeS_{522} , FeS_{523} , FeS_{524} , FeS_{525} , FeS_{526} , FeS_{527} , FeS_{528} , FeS_{529} , FeS_{530} , FeS_{531} , FeS_{532} , FeS_{533} , FeS_{534} , FeS_{535} , FeS_{536} , FeS_{537} , FeS_{538} , FeS_{539} , FeS_{540} , FeS_{541} , FeS_{542} , FeS_{543} , FeS_{544} , FeS_{545} , FeS_{546} , FeS_{547} , FeS_{548} , FeS_{549} , FeS_{550} , FeS_{551} , FeS_{552} , FeS_{553} , FeS_{554} , FeS_{555} , FeS_{556} , FeS_{557} , FeS_{558} , FeS_{559} , FeS_{560} , FeS_{561} , FeS_{562} , FeS_{563} , FeS_{564} , FeS_{565} , FeS_{566} , FeS_{567} , FeS_{568} , FeS_{569} , FeS_{570} , FeS_{571} , FeS_{572} , FeS_{573} , FeS_{574} , FeS_{575} , FeS_{576} , FeS_{577} , FeS_{578} , FeS_{579} , FeS_{580} , FeS_{581} , FeS_{582} , FeS_{583} , FeS_{584} , FeS_{585} , FeS_{586} , FeS_{587} , FeS_{588} , FeS_{589} , FeS_{590} , FeS_{591} , FeS_{592} , FeS_{593} , FeS_{594} , FeS_{595} , FeS_{596} , FeS_{597} , FeS_{598} , FeS_{599} , FeS_{600} , FeS_{601} , FeS_{602} , FeS_{603} , FeS_{604} , FeS_{605} , FeS_{606} , FeS_{607} , FeS_{608} , FeS_{609} , FeS_{610} , FeS_{611} , FeS_{612} , FeS_{613} , FeS_{614} , FeS_{615} , FeS_{616} , FeS_{617} , FeS_{618} , FeS_{619} , FeS_{620} , FeS_{621} , FeS_{622} , FeS_{623} , FeS_{624} , FeS_{625} , FeS_{626} , FeS_{627} , FeS_{628} , FeS_{629} , FeS_{630} , FeS_{631} , FeS_{632} , FeS_{633} , FeS_{634} , FeS_{635} , FeS_{636} , FeS_{637} , FeS_{638} , FeS_{639} , FeS_{640} , FeS_{641} , FeS_{642} , FeS_{643} , FeS_{644} , FeS_{645} , FeS_{646} , FeS_{647} , FeS_{648} , FeS_{649} , FeS_{650} , FeS_{651} , FeS_{652} , FeS_{653} , FeS_{654} , FeS_{655} , FeS_{656} , FeS_{657} , FeS_{658} , FeS_{659} , FeS_{660} , FeS_{661} , FeS_{662} , FeS_{663} , FeS_{664} , FeS_{665} , FeS_{666} , FeS_{667} , FeS_{668} , FeS_{669} , FeS_{670} , FeS_{671} , FeS_{672} , FeS_{673} , FeS_{674} , FeS_{675} , FeS_{676} , FeS_{677} , FeS_{678} , FeS_{679} , FeS_{680} , FeS_{681} , FeS_{682} , FeS_{683} , FeS_{684} , FeS_{685} , FeS_{686} , FeS_{687} , FeS_{688} , FeS_{689} , FeS_{690} , FeS_{691} , FeS_{692} , FeS_{693} , FeS_{694} , FeS_{695} , FeS_{696} , FeS_{697} , FeS_{698} , FeS_{699} , FeS_{700} , FeS_{701} , FeS_{702} , FeS_{703} , FeS_{704} , FeS_{705} , FeS_{706} , FeS_{707} , FeS_{708} , FeS_{709} , FeS_{710} , FeS_{711} , FeS_{712} , FeS_{713} , FeS_{714} , FeS_{715} , FeS_{716} , FeS_{717} , FeS_{718} , FeS_{719} , FeS_{720} , FeS_{721} , FeS_{722} , FeS_{723} , FeS_{724} , FeS_{725} , FeS_{726} , FeS_{727} , FeS_{728} , FeS_{729} , FeS_{730} , FeS_{731} , FeS_{732} , FeS_{733} , FeS_{734} , FeS_{735} , FeS_{736} , FeS_{737} , FeS_{738} , FeS_{739} , FeS_{740} , FeS_{741} , FeS_{742} , FeS_{743} , FeS_{744} , FeS_{745} , FeS_{746} , FeS_{747} , FeS_{748} , FeS_{749} , FeS_{750} , FeS_{751} , FeS_{752} , FeS_{753} , FeS_{754} , FeS_{755} , FeS_{756} , FeS_{757} , FeS_{758} , FeS_{759} , FeS_{760} , FeS_{761} , FeS_{762} , FeS_{763} , FeS_{764} , FeS_{765} , FeS_{766} , FeS_{767} , FeS_{768} , FeS_{769} , FeS_{770} , FeS_{771} , FeS_{772} , FeS_{773} , FeS_{774} , FeS_{775} , FeS_{776} , FeS_{777} , FeS_{778} , FeS_{779} , FeS_{780} , $\$

(2) A mineral with a granular surface often appears to be scratched when the grains have been rubbed apart or crushed.

(3) A mineral of a crystalline nature may leave a fine, white ridge on a surface, as of quartz, which can be mistaken for a scratch of a crystalline mineral.

(4) A crystalline mineral, as often of glass, scratched at the edge of another of the same species or of a different one.

The metals should be treated in such a way as to indicate their properties as little as possible.

298. Tenacity Minerals may be either brittle, sectile, malleable, or flexible.

(a) *Brittle* when parts of a mineral separate in powder or grains on being plucked out, as calcite.

(b) *Sectile* when pieces may be cut off with a knife without falling to powder but still the mineral pulverizes under a hammer. This character is intermediate between brittle and malleable as gypsum.

(c) *Malleable* when scales may be cut off and the scales flattened out under a hammer, native gold, native silver.

(d) *Flexible* when the mineral will bend without breaking and remain bent after the bending force is removed, as iron.

The tenacity of a substance is properly a consequence of its elasticity.

299. Elasticity — The elasticity of a solid body expresses its power the resistance which it offers to a change of shape or volume, and also its tendency to return to its original shape when the external force ceases to act. If the limit of elasticity is not passed the change of position is perfectly reversible, and the former shape or volume is exactly resumed. If this limit is exceeded the deformation becomes permanent, a new position of equilibrium is reached, having no resemblance to the position of the phenomenon of passing from a solid to a liquid. This is already discussed. The necessity of a rigid substance to be used as a standard of elasticity or, better, the coefficient of elasticity. This is defined as the relation between the elongation of a body and the force which produces it, or the pressure. Its effect is similar to the bending of a wire. The subject has been investigated extensively by scientists in recent years, Voigt and others have made important discoveries of the elasticity of many substances and of the crystals. The coefficient of elasticity of a material is not constant, it varies with change of crystal group, pressure, temperature, etc.

The distinction between elastic and non-elastic is very made between the species of a certain group and other minerals. Most of the minerals in description are highly elastic, and the plasticity is not so. In the case of a mineral in the physical sense of it in several cases, high value for the coefficient of elasticity is given, as either in the fact that its elasticity is a property of high magnitude, or in the fact that its elasticity

Lithograph

Hartmann

Serbeck, Skizzenatlas. Programm der Central-Anstalt für Naturkunde 1883

Franz, Pogg. 80, 37, 1850

Graebner, Pogg. Ber. Ak. Wien, 13, 410, 1854

Graebner, Pogg. Ber. Ak. Wien, 13, 410, 1854

Schubert, Pogg. 137, 17, 1854

Exner, über die Härte der Krystallkörper, 186, 1 p. Vienna, 1873 (Preisverhandl.)

Wagner, Akad.

The statement that the specific gravity of graphite is 2, of corundum 4, of galena 7.5, etc., means that the densities of the minerals named are 2, 4, and 7.5, etc., times that of water, in other words, as familiarly expressed, as 3 volume of them, a cubic inch for example, weighs 2 times, 4 times, 7.5 times, etc., as much as a like volume, a cubic inch, of water.

Strictly speaking since the density of water varies with its expansion or contraction under change of temperature, the comparison should be made with water at a fixed temperature, namely 4°C . (39.2°F), at which it has its maximum density. If made at a higher temperature a suitable correction should be introduced by calculation. Practically, however, since a high degree of accuracy is not often called for and indeed in many cases is impracticable to obtain, in consequence of the nature of the material at hand, in the ordinary work of obtaining the specific gravity of minerals the temperature at which the observation is made can safely be neglected. Common variations of temperature would seldom affect the value of the specific gravity to the extent of one unit in the third decimal place.

For the same reason, it is not necessary to take into consideration the fact that the observed weight of a fragment of a mineral is less than its true weight by the weight of air displaced.

Where the nature of the investigation calls for an accurate determination of the specific gravity (e.g., to four decimal places), no such corrections in regard to the purity of material, extremes of weight, immersion temperature, etc., can be neglected*. The accurate values spoken of are needed in the examination of such problems as the specific volume, the relation of molecular volume to specific gravity, and many others.

301. Determination of the Specific Gravity by the Balance—The direct comparison by weight of a certain volume of the given mineral with an equal volume of water is not often practicable. By the use, however, of a familiar principle in hydrostatics, viz., that a solid immersed in water is, in consequence of the buoyancy of the latter, less in weight in amount, which is equal to the weight of an equal volume of the water displaced, the determination of the specific gravity becomes a very simple process.

The weight of the solid in the air (w) is first determined in the usual manner, then the weight in water is found (w_1), the difference between these weights, that is, the loss by immersion, $w - w_1$, is the weight of a volume of water equal to that of the solid, finally the quotient of the first weight w by that of the equal volume of water as determined $w - w_1$, is the specific gravity (G).

Hence,

$$G = \frac{w}{w - w_1}$$

A common method of obtaining the specific gravity of a firm fragment of a mineral is as follows: First weigh the specimen accurately on a good chemical balance. Then suspend it from one pan of the balance by a fine hair or silk thread, or, better still, by a fine platinum wire, in a glass of water conveniently placed beneath, and take the weight again with the same care, then use the results as above directed. The platinum wire may be wound around the

* Cf. *Fact of Berkeley in Min. Mag.*, 11, 64, 1895.

specimen, or where the latter is small it may be made at one end into a little spiral support.

302. The Jolly Balance. Instead of using an ordinary balance and determining the actual weight, the spring balance of Jolly shown in Fig. 531, may be conveniently employed. This is also suitable when the mineral is in the form of small grains. The instrument consists of a spiral spring and the lower end of which is suspended two pan or wire baskets, *c* and *d*, Fig. 531. Upon the movable *c* rests a beaker filled with water. When in adjustment for reading this stand has such a position that the pan *d* is immersed in the water while *c* rides above it. Upon the upright *A* there is a mirror upon which are marked a scale. The position of the balance at any time is obtained by so placing the eye that the beam, *m*, and its reflection in the mirror coincide and then reading the position of the top of the beam upon the scale. The first step in the operation consists in getting the position of the spring alone, leaving the pan *d* immersed in the water in the beaker. Let this reading be represented by *n*. The mineral whose specific gravity is to be determined is then placed on the pan or basket *c* and the platform *B* raised until *d* is properly immersed in the water. The position of the beam *m* is again read. Let this value be represented by *N*. If from *N* be subtracted the number *n*, expressing the amount to which the scale stretches, *N* the weight of spring and pan alone, the difference will be proportional to the weight of the mineral. Next the mineral is placed in the lower pan *d*, immersed in the water and again the corresponding scale number *N₂* read. The difference between these readings (*N* - *N₂*) is a number proportional to the loss of weight in water. The specific gravity is then

$$G = \frac{N}{N - N_2} = \frac{n}{N_2}$$



Spring or
Jolly Balance
For Specific Gravity

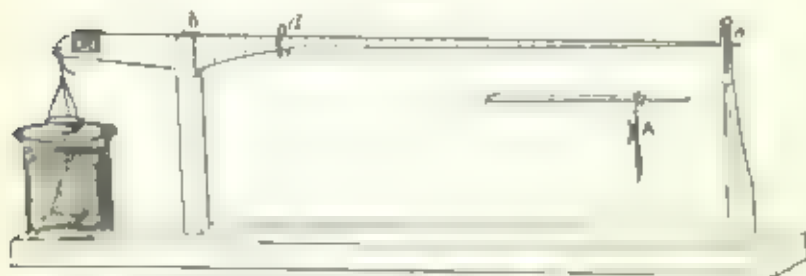
It is obviously necessary to have the wires supporting the lower pan immersed to the same depth in the case of each of the three determinations. If care is taken the specific gravity can be determined accurately in two thermal phases. A more improved form of this balance has been devised by Kewenau (see reference below).

303. The Beam Balance. A beam balance described by Penfield is neither very simple and quite accurate device for measuring the specific gravity. It is described in Fig. 532 which will make clear its essential parts. The beam is so balanced by a weight on its shorter end that it is very nearly in equilibrium when the lower pan is immersed in water. An exact balance is then obtained by the small rider *d*. When the beam is once balanced this rider is kept stationary and its position disregarded in the subsequent readings. The mineral is first placed in the upper pan and the beam balanced by another rider of equal weight that its position will be near the outer end of the beam. The position of this rider is then read from the scale engraved upon the beam. Let this value be equal to *N₁*. The mineral is next transferred to the lower pan and the beam again brought into balance by moving this same rider back.

The second reading may be represented by V . The formula for obtaining the specific gravity is now:

$$G = \frac{N}{N_1 - N_2}$$

532



Beam Balance for Specific Gravity, 2d. Natural Size (after Peacock)

304. Pycnometer — If the mineral is in the form of grains or small fragments the specific gravity may be obtained by use of the *pycnometer*. This is a small bottle (Fig. 533) having a stopper which fits tightly and contains a tube with a very fine opening. A number of different types of bottles are used. The bottle is filled with distilled water, the stopper inserted, and the overflowing water carefully removed with a soft cloth and then weighed. The mineral whose density is to be determined is also weighed. Lastly, the bottle is weighed with the mineral in it and filled with water as described above.*



Pycnometer

The weight of the water displaced by the mineral is a measure the difference between this last weight and that of the bottle filled with water plus the weight of the mineral. The specific gravity of the mineral is equal to its weight above divided by the weight of the water volume of water thus determined. Where this method is followed with sufficient care, especially avoiding any change of temperature in the water, the results may be highly accurate.

If the mineral forms porous masses, it may be first reduced to powder, but it is to be noted that it has been shown by Rose that chemical precipitates have uniformly a higher density than bakings of the same substance in a less finely divided state. This increase of density also characterizes, though to less extent, a mineral in a fine state of mechanical subdivision. It is explained by the concentration of the water on the surface of the powder.

306. Use of Liquids of High Density — It is often found convenient both in the determination of the specific gravity and in the mechanical separation of fragments of different specific gravities (e.g., to obtain pure material for analysis, or again in the study of rocks), to use a liquid of high density.

* Care should be taken to prevent air bubbles being included among the mineral particles. This may be accomplished by placing the water in an air pump and exhausting the air of it by suspending the bottle for a short time in a beaker filled with boiling water and then allowing it to cool again before weighing.

that is a so-called *heavy solution*. One of these is the solution of mercuric iodide in potassium iodide, called the Sonstadt or Thoulet solution. When made with care it has a maximum density of nearly 3.2, which by dilution may be lowered at will.

A second solution, often employed, is the *Klein solution*, the borotungstate of cerium, having a maximum density of 3.6. This again may be lowered at will by dilution, observing certain necessary precautions. Still a third solution of much practical value is that proposed by Bratus, methylene iodide, which has a specific gravity of 3.324. Carrier solution, composed of equal parts of thallium formate and malonate, has specific gravities above 4.00, see below under literature. A number of other solutions more or less practical have also been suggested.* When one of these liquids is to be used for the determination of the specific gravity of fragments of a certain mineral it must be diluted until the fragments just float and the specific gravity then obtained, most conveniently by the Westphal balance (Art. 306).

When, on the other hand, the liquid is to be used for the separation of the fragments of two or more minerals mixed together, the material is first reduced to the proper degree of fineness, the dust and smallest fragments being sifted out, then it is introduced into the solution and this diluted until one constituent after another sinks and is removed. For the convenient application of this method, a suitable tube is called for and certain precautions must be observed, see the papers cited in the literature, p. 222, especially one by Penfield.

306 Westphal's Balance. The Westphal balance is conveniently used to determine the specific gravity of a liquid, and hence of a mineral when a heavy solution is employed (Art. 305). It consists essentially of a graduated steel beam, pivoted at one end, which is suspended by a fine wire. The arm is so weighted at the pivot point that it is either a perfectly balance or the arm is horizontal. A glass tube containing the liquid whose specific gravity is to be determined is drawn so that an sinker of known weight is placed in order to adjust the arm weights in the form of riders are placed upon the graduated arm. These riders are so placed that the sinker is just supported, and the gravity of the liquid is the reciprocal of the arm position. The position of the sinker is shown by the arm position on the graduated scale. The position of the sinker is shown by the arm position on the graduated scale. The position of the sinker is shown by the arm position on the graduated scale.

307 Relation of Density to Hardness, Chemical Composition, etc. The density of a mineral depends first upon the nature of the chemical substance which it contains and second upon the state of aggregation.

Thus, anhydrous silicates of the heavy metal ions, such as lead, have a high density (e.g., about 8.3) while lead in a heavy metal, or chemically expressed, has a high atomic weight (207.2). Similarly, carbon dioxide has a high density (1.977), while carbon monoxide or anhydride the value is only 2.165 atomic weight or less as 1.17, for carbon dioxide is 44.

On the other hand, while a mineral is a metal of low density (e.g., 2.5 and atomic weight 11), it is a metal, or more correctly, has a high density (e.g., 19.3 and atomic weight 112). Again, carbon (atomic weight = 12) has a high density in the diamond form (3.5) and low in graphite (2.2), also the same is true of the same element in the same form. In these and similar cases the high density is due to great hardness and hence to a high atomic weight and it should be accompanied by great hardness and hence to a high density.

In bearing upon this point it is to be noted that the density of many substances is affected by form. Again, the same mineral in different forms of aggregation may differ but only slightly in density. Furthermore, substances having the same chemical composition have sometimes different densities, corresponding to the different crystalline

* Lohmann, *Manual of Petrographic Methods*, p. 519 of my, given in detail an account of the various solutions, the methods of their preparation, etc.

- Helgerz. Jb. Min. 2, 185, 1889.
 Salomon. Jb. Min. 2, 1891.
 Peabody. Am. J. Sc. 60, 137, 1895.
 Merwin. Am. J. Sc. 52, 1, 1911.
 Vasear. Law and formation of (lens) solution. Am. Min. 10, 123, 1925.

III CHARACTERS DEPENDING UPON LIGHT

GENERAL PRINCIPLES OF OPTICS

311. Before considering the optical characters of minerals in general and more particularly those that are owing to the crystals of the different systems, it is desired to review briefly some of the more important principles of optics upon which the phenomena in question depend.

For a fuller treatment of the optics of crystals, special reference is made to the works of Great. Treatise on Optics, Jackson, Jackson, Mich. Dupré and Penrose. (Lancaster) translation by Vol. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99, 100, 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111, 112, 113, 114, 115, 116, 117, 118, 119, 120, 121, 122, 123, 124, 125, 126, 127, 128, 129, 130, 131, 132, 133, 134, 135, 136, 137, 138, 139, 140, 141, 142, 143, 144, 145, 146, 147, 148, 149, 150, 151, 152, 153, 154, 155, 156, 157, 158, 159, 160, 161, 162, 163, 164, 165, 166, 167, 168, 169, 170, 171, 172, 173, 174, 175, 176, 177, 178, 179, 180, 181, 182, 183, 184, 185, 186, 187, 188, 189, 190, 191, 192, 193, 194, 195, 196, 197, 198, 199, 200, 201, 202, 203, 204, 205, 206, 207, 208, 209, 210, 211, 212, 213, 214, 215, 216, 217, 218, 219, 220, 221, 222, 223, 224, 225, 226, 227, 228, 229, 230, 231, 232, 233, 234, 235, 236, 237, 238, 239, 240, 241, 242, 243, 244, 245, 246, 247, 248, 249, 250, 251, 252, 253, 254, 255, 256, 257, 258, 259, 260, 261, 262, 263, 264, 265, 266, 267, 268, 269, 270, 271, 272, 273, 274, 275, 276, 277, 278, 279, 280, 281, 282, 283, 284, 285, 286, 287, 288, 289, 290, 291, 292, 293, 294, 295, 296, 297, 298, 299, 300, 301, 302, 303, 304, 305, 306, 307, 308, 309, 310, 311, 312, 313, 314, 315, 316, 317, 318, 319, 320, 321, 322, 323, 324, 325, 326, 327, 328, 329, 330, 331, 332, 333, 334, 335, 336, 337, 338, 339, 340, 341, 342, 343, 344, 345, 346, 347, 348, 349, 350, 351, 352, 353, 354, 355, 356, 357, 358, 359, 360, 361, 362, 363, 364, 365, 366, 367, 368, 369, 370, 371, 372, 373, 374, 375, 376, 377, 378, 379, 380, 381, 382, 383, 384, 385, 386, 387, 388, 389, 390, 391, 392, 393, 394, 395, 396, 397, 398, 399, 400, 401, 402, 403, 404, 405, 406, 407, 408, 409, 410, 411, 412, 413, 414, 415, 416, 417, 418, 419, 420, 421, 422, 423, 424, 425, 426, 427, 428, 429, 430, 431, 432, 433, 434, 435, 436, 437, 438, 439, 440, 441, 442, 443, 444, 445, 446, 447, 448, 449, 450, 451, 452, 453, 454, 455, 456, 457, 458, 459, 460, 461, 462, 463, 464, 465, 466, 467, 468, 469, 470, 471, 472, 473, 474, 475, 476, 477, 478, 479, 480, 481, 482, 483, 484, 485, 486, 487, 488, 489, 490, 491, 492, 493, 494, 495, 496, 497, 498, 499, 500, 501, 502, 503, 504, 505, 506, 507, 508, 509, 510, 511, 512, 513, 514, 515, 516, 517, 518, 519, 520, 521, 522, 523, 524, 525, 526, 527, 528, 529, 530, 531, 532, 533, 534, 535, 536, 537, 538, 539, 540, 541, 542, 543, 544, 545, 546, 547, 548, 549, 550, 551, 552, 553, 554, 555, 556, 557, 558, 559, 560, 561, 562, 563, 564, 565, 566, 567, 568, 569, 570, 571, 572, 573, 574, 575, 576, 577, 578, 579, 580, 581, 582, 583, 584, 585, 586, 587, 588, 589, 590, 591, 592, 593, 594, 595, 596, 597, 598, 599, 600, 601, 602, 603, 604, 605, 606, 607, 608, 609, 610, 611, 612, 613, 614, 615, 616, 617, 618, 619, 620, 621, 622, 623, 624, 625, 626, 627, 628, 629, 630, 631, 632, 633, 634, 635, 636, 637, 638, 639, 640, 641, 642, 643, 644, 645, 646, 647, 648, 649, 650, 651, 652, 653, 654, 655, 656, 657, 658, 659, 660, 661, 662, 663, 664, 665, 666, 667, 668, 669, 670, 671, 672, 673, 674, 675, 676, 677, 678, 679, 680, 681, 682, 683, 684, 685, 686, 687, 688, 689, 690, 691, 692, 693, 694, 695, 696, 697, 698, 699, 700, 701, 702, 703, 704, 705, 706, 707, 708, 709, 710, 711, 712, 713, 714, 715, 716, 717, 718, 719, 720, 721, 722, 723, 724, 725, 726, 727, 728, 729, 730, 731, 732, 733, 734, 735, 736, 737, 738, 739, 740, 741, 742, 743, 744, 745, 746, 747, 748, 749, 750, 751, 752, 753, 754, 755, 756, 757, 758, 759, 760, 761, 762, 763, 764, 765, 766, 767, 768, 769, 770, 771, 772, 773, 774, 775, 776, 777, 778, 779, 780, 781, 782, 783, 784, 785, 786, 787, 788, 789, 790, 791, 792, 793, 794, 795, 796, 797, 798, 799, 800, 801, 802, 803, 804, 805, 806, 807, 808, 809, 810, 811, 812, 813, 814, 815, 816, 817, 818, 819, 820, 821, 822, 823, 824, 825, 826, 827, 828, 829, 830, 831, 832, 833, 834, 835, 836, 837, 838, 839, 840, 841, 842, 843, 844, 845, 846, 847, 848, 849, 850, 851, 852, 853, 854, 855, 856, 857, 858, 859, 860, 861, 862, 863, 864, 865, 866, 867, 868, 869, 870, 871, 872, 873, 874, 875, 876, 877, 878, 879, 880, 881, 882, 883, 884, 885, 886, 887, 888, 889, 890, 891, 892, 893, 894, 895, 896, 897, 898, 899, 900, 901, 902, 903, 904, 905, 906, 907, 908, 909, 910, 911, 912, 913, 914, 915, 916, 917, 918, 919, 920, 921, 922, 923, 924, 925, 926, 927, 928, 929, 930, 931, 932, 933, 934, 935, 936, 937, 938, 939, 940, 941, 942, 943, 944, 945, 946, 947, 948, 949, 950, 951, 952, 953, 954, 955, 956, 957, 958, 959, 960, 961, 962, 963, 964, 965, 966, 967, 968, 969, 970, 971, 972, 973, 974, 975, 976, 977, 978, 979, 980, 981, 982, 983, 984, 985, 986, 987, 988, 989, 990, 991, 992, 993, 994, 995, 996, 997, 998, 999, 1000.

312. The Nature of Light. Light is now considered to be an electromagnetic phenomenon due to a periodic variation in the energy given off by vibrating electrons. This energy is transmitted by a series of periodic charges that show all the characters of ordinary wave phenomena. The light waves, as they are commonly called, possess certain short wavelengths that are of the correct magnitude to affect the optic nerves. Other shorter waves with longer or shorter wavelengths belong to the same class of phenomena. Immediately beyond the violet end of the visible spectrum come the so-called "ultra-violet" waves with still shorter wavelengths and on beyond these we have the X-rays and the "gamma" rays produced by radium. Of the waves having greater lengths than those of light waves we have the waves that give rise to the sensation of heat and the Hertzian waves used in wireless. All of these vibrations, while varying enormously in their wavelengths, belong to the same order of phenomena and obey the same laws. The proportion that the sector of the series which produces the effect of light bears to the whole may be strikingly shown when we say that for ordinary white light is broken up into a spectrum several inches long and thus then considered to be extended on either end so as to include all known electromagnetic waves the entire spectrum would be over five million miles in length.

The transmission of light through interstellar space, through liquids and transparent solids, has for some time been explained by the assumption that a medium, called the luminiferous ether pervades all space including the intermedium or space of material bodies. In this medium the vibrations of light waves are assumed to take place. For the purposes of the present work, however, it is unnecessary to consider closely the exact nature of light or the mode of its transmission. It will assist greatly, however, in obtaining a clear idea of the behavior of light in crystals if we assume that light waves are mechanical in nature and consist of periodic vibrations or oscillations in an all-pervading ether.

313. Wave-motion in General.—A familiar example of wave-motion is given by the series of concentric waves which on a surface of smooth water go out from a center of disturbance, as the point where a pebble has been dropped in. These surface-waves are propagated by a motion of the water-

particles which is transverse to the direction in which the waves themselves travel, the motion is given from each particle to the next adjoining, and so on. Thus the particles of water at any one spot oscillate up and down,* while the wave moves on as a circular ridge of water of constantly increasing diameter but of diminishing height. The ridge is followed by a valley, indeed both together properly constitute a wave in the physical sense. This compound wave is followed by another wave and another, until the original impulse has exhausted itself.

Another familiar kind of wave-motion is illustrated by the sound-waves which in the free air travel outward from a sonorous body in the form of concentric spheres. Here the actual motion of the layers of air is forward and back, that is, in the direction of propagation of the sound, and the effect of the transfer of this impulse from one layer to the next is to give rise alternately to a condensed and a rarefied shell of air, which together constitute a sound-wave and which expand in spherical waves of constantly decreasing intensity until the mass of air set in motion continually increases. Sound-waves in air of the voice, may be several feet in length, and they travel at a rate of 1120 feet per second at ordinary temperatures.

314. It is important to understand that in both the cases mentioned as in every case of free wave-motion, each point on a given wave may be considered as a center of disturbance from which a system of new waves tend to go out. These individual wave-systems ordinarily destroy each other except so far as the onward progression of the wave as a whole is concerned. This is further illustrated and illustrated in its application to light-waves (Art. 316 and Figs. 535, 536).

In general, therefore, a given wave is to be considered as the resultant of all these minor wave-systems. If, however, a wave encounters an obstacle in its path, as a narrow opening, i. e., one narrow in comparison with the length of the wave, or a sharp edge, then the fact just mentioned explains how the waves seem to bend about the obstacle, since new waves start from them as centers. This principle has an important application in the case of light-waves, explaining the phenomena of diffraction (Art. 337,

315. Still another case of wave-motion may be mentioned, more especially helpful in explaining a series of important cases of light-phenomena. If a long rope stretched at one end be propagated in a straight line, motion of the hand up or down will communicate a half a motion to one end of the rope, the other a trough, while the travel quickly to the other end, and no reflection back with a reversal of the motion, that is, if it were to travel back a hump or wave, it will reflect as a trough. If, just as the wave has run half the rope, a second motion be started, that is, a second and equal motion of the hand, it will then for a brief interval be repeated as a half of each of both two up and down, a complete motion. This may be seen after the manner of the water-pipe interference (Fig. 537) in waves exposed to a plane.

Again, if double motion of the hand, up and down, be produced in a rope wave, with rest and trough, and a hump, no change of motion is reflected back as a hump or trough, but a wave of a series of like motions are contained in the rope, and so motion that each wave may be said to be the whole of the two motions of equal and opposite waves passing to the two directions with rest and a hump or trough, and a trough or valley, waves will be the result, the rope seeming to divide in segments to and fro about the position of equilibrium.

Finally, if the rope be made to describe a small circle at a rapid, uniform, rotation, that is, a system of rotary waves will appear, but now the vibrations of the string will be mainly in circles about the central line. This last case will be seen to be a circular trough, the kind of transverse vibration by which the waves of circularly polarized light are propagated, while the former case represents the vibrations of waves of what is called plane-polarized light.

* Strictly speaking, the path of each particle approximates closely to a circle.

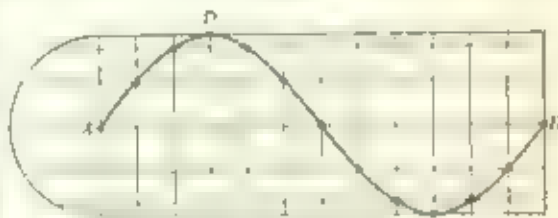
All three cases of waves obtained with a rope deserve to be carefully considered and studied by experiment for the sake of the assistance they give to an understanding of the complex phenomena of light-waves.

316. Light-waves. In the discussion that follows, in order to make the explanations simpler and clearer, light-waves have been treated as if they consisted of mechanical disturbances in a material medium called ether.

The vibrations in the ether caused by the transmission of a light-wave take place in directions transverse to the direction of the movement of the wave. These oscillations have the following characters. When an ether particle is set vibrating it moves from its original position with gradually decreasing velocity until the position of its maximum displacement is reached. Then with gradually increasing velocity it returns to its original position and since it is moving without friction it will continue in the same direction on past this point. Its velocity will then again diminish until it has reached a displacement equal but opposite in direction to its first swing, where it will start back on its course and repeat the oscillation. The varying velocity of such an oscillation would be the same as that shown by a particle moving around a circle with uniform speed if the particle was observed in a direction lying in the plane of the circle. Under these conditions the particle would appear to move forward and backward along a straight line with constantly changing velocity. Such a motion is called *simple harmonic motion*.

The motion of one ether particle is communicated to another and so on each in order taking a time bounded in the time of its oscillation. Consequently, while the individual particles move only back and forth in the same

line the wave disturbance moves forward. If, at a given instant of time, the positions of successive particles in their oscillations are plotted, a curve will, as shown in Fig. 534, will be formed. Such a curve is known as a *harmonic curve*.



Harmonic curve

The oscillatory motion of the particles in a light-wave is called a *periodic motion* since it repeats itself at regular intervals. The maximum displacement of a particle from its original position (Fig. 534) is called the *amplitude* of the wave (distance CD Fig. 534). The *phase* of a particle at a given instant is its position in the vibration and the direction in which it is moving.

The distance between any particle and the next which is in a like position (Fig. 534) is the *wave-length*, and the time required for the completed movement is the *time of vibration*, or *vibration-period*. The wave-sin then travels onward the distance of one wave-length in one vibration-period. The intensity of the light varies with the square of the amplitude of the vibration, and the color as explained in a later article, depends upon the region of the waves: the length of the violet waves is about one half the length of the red waves.

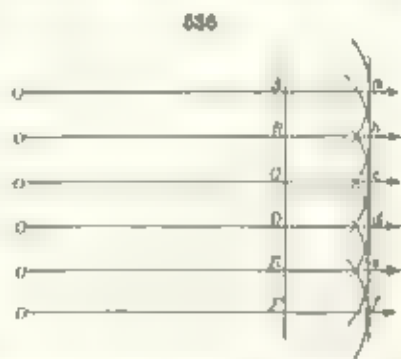
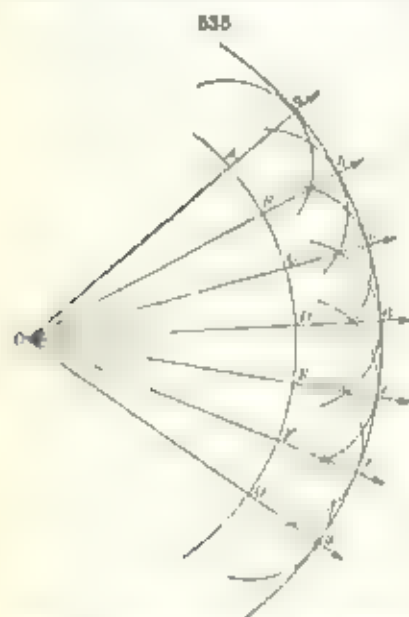
In ordinary light the transverse vibrations are to be thought of as taking place in all planes about the line of propagation. In the above figure, vibra-

tions in one plane only are represented. Light that has only one direction of transverse vibration is said to be *plane-polarized*.

Light-waves have a very minute length, only 0.000023 of an inch for the yellow sodium flame and they travel with enormous velocity, 186,000 miles per second in a vacuum, thus light passes from the sun to the earth in about eight minutes. The vibration-period, or time of one oscillation, is consequently extremely brief. It is given by dividing the distance traveled by light in one second by the number of waves included.*

317 Wave-front. In an isotropic medium, as air, water, or glass — that is, one in which light would be propagated in all directions about a luminous point with the same velocity

the waves are spherical in form. The *wave-front* is the continuous surface in this case spherical, which reaches all particles that commence their vibration at the same moment of time. Obviously the curvature of the wave-front diminishes as the distance from the source of light increases, and when the light comes



from an indefinitely great distance (as the sun) the wave-front becomes sensibly a plane surface. Such waves are usually called *plane waves*. These cases are illustrated by Figs. 535 and 536. In Fig. 535 the luminous point is supposed to be O , and no medium being outside it is obvious that the wave-front, as AB , CD , EF , etc., is spherical. It is also made clear by this figure how, as briefly stated in Art. 314, the resultant of all the individual impulses which go out from the successive points as A , B , C , etc., as centers, forms a new wave-front, the AB , concentric with AB , CD , etc. In Fig. 536 the luminous body is supposed to be at a great distance, so that the wave-

* On account of the tremendous speed at which light travels the quantity of vibration or frequency of light as it passes through a fixed point is extremely great. About eight hundred trillion waves of violet light would pass through such a point in a second. The extreme brevity of the interval of time required for a passage of a single wave of this sort may perhaps be realized better when it is said that one eight hundred trillionth of a second is a vastly smaller part of a second than a second is of the whole of historic time. *Coomstock and Frothingham, The Nature of Matter and Electricity*, p. 157.

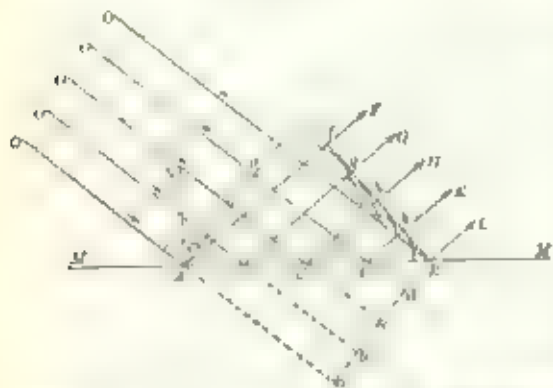
also do not affect the eye. The former are called *infra-red*, the latter *ultra-violet* waves.

The *brightness* of light depends upon the amplitude of its vibrations and varies directly as the square of the distance.

320 Complementary Colors. The sensation of white light mentioned above is also obtained when to a given color

that is light waves of given wave-length is combined a certain (rather so-called) *complementary color*. Thus certain shades of pink and green combined, as by the rapid rotation of a card on which the colors form segments, produce the effect of white. Blue and yellow of certain shades are also complementary. For every shade of color in the spectrum there is another etc. complementary to it in the sense here defined. The most perfect illustration of complementary colors is given by the

537

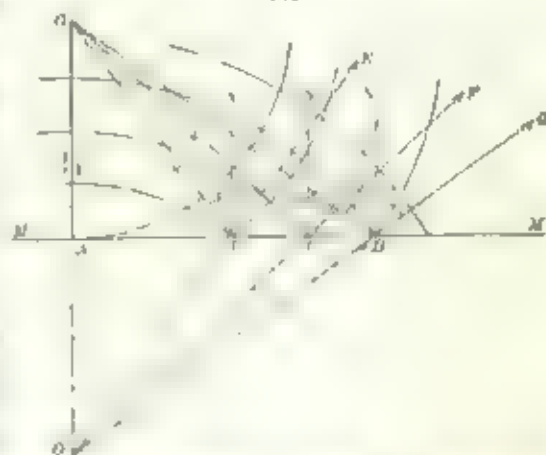


axis rotation of some one of crystals in polarized light after experiments.

321. Reflection. When light waves come to the boundary which separates one medium from another as a surface of water or glass, etc., they are, in general, in part reflected or returned back into the first medium.

The reflection of light-waves is illustrated by Figs. 537 and 538. In Fig. 537, MM' is the reflecting surface—here a plane surface—and the light-waves have a plane wave front. (Here in other words, the light-rays (OA, OB , etc.) are parallel. It is obvious that the wave-front meets the surface first at A and then at B , as it goes from point to point. These points are to be regarded as the centers of new wave-systems which unimpeded would be propagated outward in all directions and as a given point would have traveled through distances equal to the lines AO, BO , etc. Hence a common tangent ghh' to the circular arcs drawn and those from A, B , etc., represents the direction of the new or reflected wave-front. But geometrically the angle gAE is equal to fEA , or the incident and reflected wave-

538



front as a given point would have traveled through distances equal to the lines AO, BO , etc. Hence a common tangent ghh' to the circular arcs drawn and those from A, B , etc., represents the direction of the new or reflected wave-front. But geometrically the angle gAE is equal to fEA , or the incident and reflected wave-

fronts make equal angles with the reflecting surface. If $\angle A$ is a normal at A , the angle $\angle A'AV$ called the angle of incidence is equal to $\angle AVF$, the angle of reflection. Hence the luminous ray

The angle of incidence is equal to the angle of reflection.

Furthermore, the incident and reflected rays both lie in the same plane as the normal to the reflecting surface.

In Fig. 13b, where the air flows past at U , the waves going out from A will meet the plane mirror MM' first at the point A' and successively at points, as B, C, D , etc. farther away to the right and to the left. Here also it is easy to show that in the new images there will be four centers at A', B', C', D' , and together give rise to a series of reflected waves whose center is at A' , at a distance equally great from MM' measured in a normal to the surface ($AA' = O'A'$).

Now the lines OA , OB , etc., which are perpendicular to the wave-front, represent certain incident light-rays and to eye-lenses, the points A , B , C , etc., will see the luminescent point just at O . It follows from a consideration of the figure and can be proved by experiment that $\angle AN = \angle A'$ etc. are actually the interior angles of incidence ($\angle AN = \angle N'$, etc.), are equal to the angles of reflection ($\angle BE = \angle E'$, etc.) respectively. Hence the rays now appear to the eye as if

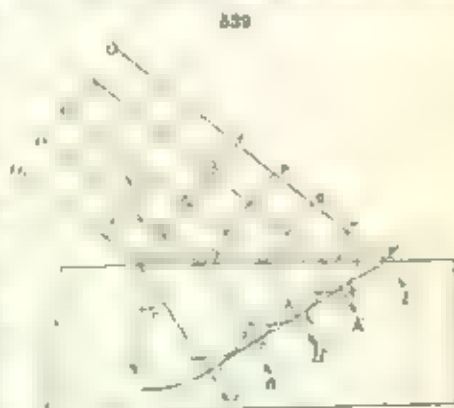
If the reflecting surface is not plane, but, for example, a spherical surface, we treat it as a sphere, or part of a sphere, rather than as being "in the curve" part of the wave front after reflection, but we cannot know where the center of the sphere is.

The projection of the vector \vec{r} of the point P on the line AB is the vector \vec{r}_1 of the point Q on the line AB . The projection of the vector \vec{r} on the line AB is the vector \vec{r}_1 of the point Q on the line AB .

The first of these is the fact that the
 IF-THEN-ELSE statement is not a primitive
 for the language. It is a derived statement
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322. Refraction. When light passes from one medium into another there is in general an increase or decrease in its velocity, and this necessarily results in a change in the direction of propagation. The principles applicable here can be easily illustrated in the case of light waves with a plane wave-front as shown in Fig. 322, where the light rays (1, 2, 3, etc.) are parallel.

light rays OA (figure 1) passing through the point A in the plane of the surface. Suppose for example that a light wave packet whose velocity is c in air, whose refractive index is n in the medium, is incident on the surface at the point A and is refracted into the medium at the point B . The distance AB is the distance that the light ray travels in the medium. The time that the light ray travels from A to B is $t = AB/c$. The distance OB is the distance that the light ray travels in the air. The time that the light ray travels from A to B is $t = OB/c$. The time that the light ray travels from A to B is $t = OB/c$. The time that the light ray travels from A to B is $t = OB/c$.



to E , the ray $O-A$ will have advanced in the glass a distance equal to $\frac{1}{2}p-E$, or to some point on an arc having this distance as a radius Af . In the same way during the time ray $O-E$ passes from the point p to E , ray $O-B$ will have travelled in the glass the distance $B-g$ equal to $\frac{1}{2}p-E$. In this way arcs may be drawn about each one of the points A, B, C , etc. and the position of the new wave-front in the glass determined by their common tangent, $Ehkf$. It is seen that there is a change of direction in the wave-front, or otherwise stated, in the light-ray, the magnitude of which depends on the ratio between the light-velocities in the two media, and, as discussed later, also upon the wave-length of the light. The light-ray is here said to be *bent* or *refracted*, and for a medium like glass, optically denser than air (i.e., with a lower value of the light-velocity) the refraction is toward the perpendicular with the angle of refraction, r , smaller than the angle of incidence, i . In the opposite case — when light passes into an optically rarer medium — the refraction is away from the perpendicular and the angle of refraction is larger than that of incidence (Art. 328).

323 Refractive Index. — It is obvious from the figure that whatever the direction of the wave-front — that is, of the light-rays — relatively to the given surface, the ratio of eE to Af , which determines the direction of the new wave-front (i.e., the direction of a refracted ray, AF) is constant. This ratio is equal to $\frac{V}{v}$, where V is the value of the light-velocity for the first medium (here air) and v for the second (as glass). This constant ratio is commonly represented by n and is known as the *index of refraction*. Therefore

$$n = \frac{eE}{Af}$$

In Fig. 539, by construction,

$$\angle eAE = \angle i \quad \text{and} \quad \angle AEf = \angle r,$$

$$\text{Also,} \quad \frac{eE}{AE} = \sin i \quad \text{and} \quad \frac{Af}{AE} = \sin r.$$

Therefore,

$$\sin i = \frac{eE}{AE} = \frac{eE}{Af} = n \sin r$$

The law of refraction then is given by the expression, $n = \frac{\sin i}{\sin r}$, or may be formulated as follows:

The sine of the angle of incidence bears a constant ratio to the sine of the angle of refraction.

In the case of light passing from air into crown glass this ratio is found to be $\frac{\sin i}{\sin r} = 1.608$, and this number consequently gives the value of the refractive index, or n , for this kind of glass.*

* Strictly speaking the index of refraction of a substance is a function of the wave-length of the light. For crown glass the index of refraction n for air = 1.0003, the index of any substance is obtained by comparison with that of air.

The above relation holds true for any wave-system of given wave-length in passing from one medium in to another, whatever the wave-front or shape of the bounding surface. In Fig. 340 the common point is at O and it can be readily shown that the new wave-front propagated in the second medium of greater optical density, has a flattened curvature and corresponding to this a center at O' (where $\frac{OA}{OA'} = \frac{1}{n}$). Here the incident rays OB , OC , are refracted at B and C , the corresponding refracted rays being BE and CF . For this case also the relation holds good,

$$n = \frac{\sin i}{\sin r} = \frac{\sin i'}{\sin r'}, \text{ etc.}$$

If the bounding surface is not plane but curved as in lenses, there is a change in the curvature of the wave-front in the second medium but the simple law, $n = \frac{\sin i}{\sin r}$, holds true here also, so long as the medium is isotropic.

The relation between wave-length and refractive index is spoken of in Art. 333.

324. Relation of Refractive Index to Light-velocity.—The discussion of the preceding article shows that if n is the refractive index of a given substance for waves of a certain length referred to air, V the velocity in air and v the velocity in the given medium, then

$$n = \frac{V}{v}$$

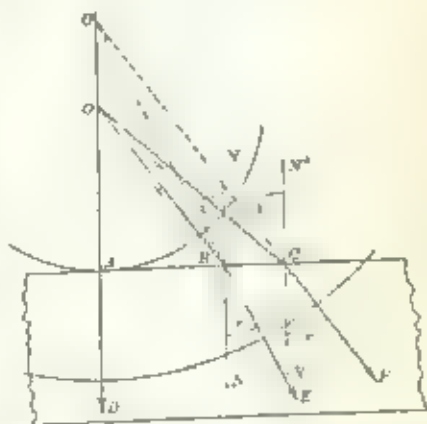
For two media whose indices are n_1 and n_2 respectively, it consequently follows that

$$\frac{n_1}{n_2} = \frac{v_2}{v_1}$$

Therefore The indices of refraction of two given media for a certain wave-length are inversely proportional to their minute light-velocities.

In other words if the velocity of light in air is taken as equal to 1 and the velocity of the same light is found to be one-half as great when passing through a given substance, the index of refraction or n_2 of that substance when referred to air $n_1 = 1.0$ will be equal to 2.0.

325. Principal Refractive Indices.—The refractive index has, as stated, a constant value for every substance, referred, as is usual, to air or it may be to a vacuum. In regard to solid media it is stated from Art. 323 and will be further explained later that those which are isotropic, i.e., amorphous substances and crystals of the isometric system, can have but a single value



of this index. Crystals of the tetragonal and hexagonal systems have as later explained *two* principal refractive indices ω and ϵ , corresponding to the velocities of light having certain definite directions of vibration. Further, all orthorhombic, monoclinic and triclinic crystals have similarly three principal indices, α , β , γ . In the latter cases of so-called anisotropic media, the mean refractive index is taken as the arithmetic mean, namely $\frac{\omega + \epsilon}{3}$

and $\frac{\alpha + \beta + \gamma}{3}$.

326 Effect of Index of Refraction upon Luster, etc.—The luster and general appearance of a transparent substance depend largely upon its refractive index. For instance the peculiar aspect of the mineral crystals by means of which it is usually possible to recognize them is due to its low index of refraction. If crystals are pulverized and the powder poured into a test tube of water it will disappear and apparently go into solution. It is quite insoluble, however, but becomes invisible in the water because its index of refraction, about 1.34, is near that of water, 1.33. The light will travel with practically the same velocity through the crystals as through the water and consequently suffer little reflection or refraction at the surfaces between the two. On the other hand powdered glass with a higher index of refraction than that of water appears white under the same conditions because of the reflection of light from the surfaces of the particles.

Substances having an unusually high index of refraction have an appearance which is sharp and lustrous and which is generally spoken of as an adamantine luster. This kind of luster may be best comprehended by examining specimens of diamond, $n = 2.419$, or of cinnabar, $n = 1.98$. They have a glass and cubic, sometimes also a metallic appearance, which is not possessed by minerals of low refractive index. Compare for example, specimens of garnet, which may be said to range not far from 1.5 at a given time, minerals of luster which has been termed vitreous. Quartz, feldspar and zircon show good examples of vitreous luster.

Below is given a list of common minerals arranged according to their indices of refraction. For numerous other lists, lists of the hexagonal system, the average value, as defined in the preceding article, is given here:

Water	1.335	Kyanite	1.723
Fluorite	1.434	Ice	1.310
Orthoclase	1.523	Calcite	1.765
Crocidolite	1.524	Andalusite	1.810
Quartz	1.547	Muscovite	1.840
Muscovite	1.582	Augite	1.894
Beryl	1.582	Zircon	1.972
Quartz	1.601	Enstatite	1.986
Feldspar	1.622	Calcite	2.029
Triclinic	1.622	Sillimanite	2.077
Dolomite	1.621	Siderite	2.360
Aragonite	1.633	Barite	2.419
Apatite	1.633	Rutile	2.711
Barite	1.649	Calcite	2.439
Diopside	1.685	Calcite	2.490

327. Relations between Chemical Composition, Density, and Refractive Index. That direct relation exists between the chemical composition of a substance and its specific gravity, and its power of refracting light, has been shown in many cases. With the single exception of graphite, it is true, the variation in composition which corresponds to the above is accompanied by a slight variation in density and refractive index. Attempts have been made to express the variation in the form of a mathematical statement. The two most satisfactory expressions are the one proposed by Chladni and Dole,* $n^2 = 1 + \frac{1}{\rho}$, ρ = constant, and the one proposed independently by Lorenz† and Lorentz‡ $n^2 = 1 + \frac{1}{\rho}$, ρ = constant. In these ρ is equal to the mean refractive index and ρ is the density. These were originally proposed for use with gases at 1 atm. and at 0° C. for these bodies have been found to serve the purpose well. Where attempts are made, however, to apply them to solids due regard to the facts are in the case of a liquid must be taken. The first of these would not take into consideration the modification that the crystal structure must introduce.

328. Total Reflection. Critical Angle. In regard to the principle stated in Art. 323 and expressed by the equation $n = \frac{\sin i}{\sin r}$, two points are to be noted. First, if the angle $i = 0^\circ$ then $\sin i = 0$, and n varies also $r = 0$, in other words, when the ray of light is at Fig. 540, whatever n is, the ray proceeds onward at 0° and the second medium without deviation but with a change of velocity.

Again, if the angle $i = 90^\circ$, then $\sin i = 1$, and the equation above becomes $n = \frac{1}{\sin r}$ or $\sin r = \frac{1}{n}$. As n has a fixed value for every substance, it is obvious that there will also be a corresponding value of the angle r for the case mentioned. From the above table it is seen that for water, $\sin r = \frac{1}{1.335}$ and $r = 48^\circ 31'$; for crown glass $n = 1.608$, $\sin r = \frac{1}{1.608}$ and $r = 38^\circ 27'$; for diamond, $\sin r = \frac{1}{2.42}$ and $r = 24^\circ 25'$.

This fact, that for each substance at a particular value of the angle r the angle i becomes equal to 90° is an important bearing on the behavior of light when it is passing from an optically denser into an optically rarer medium. In Fig. 541 we may assume that light-rays coming from various directions meet the surface between a block of glass and the air at the point A. Light traveling along the path CA will pass out into the air without a change in its direction but with an increase in its velocity. If it emerges from the glass at any other angle than 90° the ray on entering the air will be bent away from the perpendicular and the angle of deviation will vary with the angle at which the ray touches the surface and with the index of refraction of the glass. The same law holds true in this case as in the case of a ray entering from the air, except that the formula now reads $n = \frac{\sin r}{\sin i}$, where r = the angle the ray in air makes with the normal to the surface and i = the angle that the ray makes within the glass to the same normal. In Fig. 543 the ray CA will pass

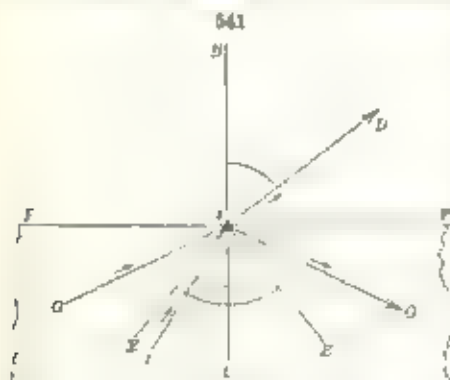
* Phil. Trans., 183, 317, 1803.

† Wied. Ann. 9, 64, 1880.

‡ Wied. Ann. 11, 70, 1880.

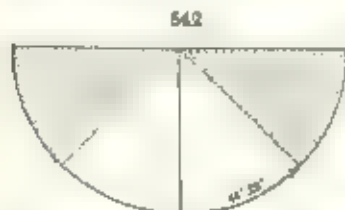
§ E. N. Lorenz, Am. Jour. Sci., 22, 263, 1900. See also Chladni, Ann. Chem. Phys. 12, 145, 2nd, 1807.

out into the air along the line $A D$. But the angle i for the ray $E A$ $38^{\circ} 27'$ and, as shown in the preceding paragraph, for glass where $n = 1.608$, the angle r in the air will be 90° and the ray will travel along the surface of the glass in the direction $A F$. Consequently any ray such as $E A$, which meets the surface of the glass at an angle greater than $38^{\circ} 27'$ will be unable to pass out into the air and will suffer total reflection at the surface, passing back into the glass in the direction $A G'$, with angle $OAG =$ angle OAQ . The angle at which total reflection takes place for any substance is known as its *critical angle*.



The phenomenon of total reflection is taken advantage of in the cutting of gem stones. According to common practice such a stone is cut with a flat surface on top and with a number of inclined

facets on the bottom. The light that enters the stone from above is in a large measure totally reflected from the sloping planes below and comes back to the eye through the stone. The amount of light reflected in this way and the consequent brilliancy of the gem increases with its index of refraction. Two stones cut exactly alike one from karnel and the other, perhaps, from quartz, would have very different appearances due to this difference in the amount of light totally reflected from their lower facets. This principle is illustrated in Figs 542 and 543. They represent cross sections of two hemispheres cut one from fluorite and the other from diamond. It is assumed that light from all directions is focused on the center of the plane surface of each hemisphere. All the light that meets this surface at an angle greater



Total Reflection in Fluorite $n = 1.43$



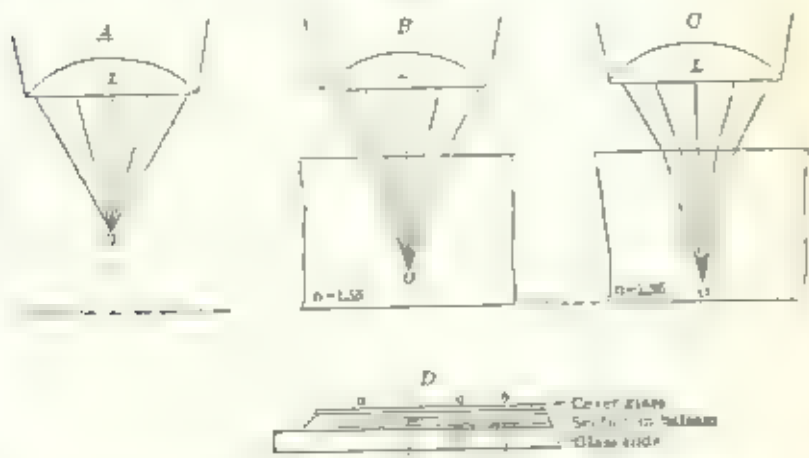
Total Reflection in Diamond $n = 2.42$

than the critical angle for the mineral will be totally reflected back through the spherical surface. The shaded areas of the figures show the amount of light in each case that would be so reflected, and clearly illustrate the optical difference between the two substances.

329. Effect of Index of Refraction upon Microscopic Phenomena. — In the study of minerals generally in thin sections under the microscope, variations in the index of refraction give effects which are of importance. In Fig 544 let it be assumed that L is the objective lens of a compound microscope and that the instrument is exactly focused upon a point O , Fig. 544 A . If

now we imagine that a section of some mineral of mean index of refraction is placed under the lens, (fig. 544 B) the point O will now be in focus or as in fig. 544 C, where the mineral is supposed to have a high index of refraction. The focus will be at O . Thus it is that with two sections of equal thickness and with the lens in the same position one must be deeper into the mineral of higher index of refraction. Consequently when there are two minerals in the same section, the one having a high and the other a low index of refraction, for example, a crystal of zircon, $n = 1.93$, encased in quartz, $n = 1.55$, the one having the higher index of refraction will apparently have the greater thickness and will appear to stand up in relief above the surface of the mineral of lower index. The apparent relief is furthermore augmented by other properties to be explained below.

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In preparing thin sections of minerals or rocks for study with the microscope the process is brief as to make first a thin surface upon the mineral or rock by grinding it upon a plate supplied with some abrasive. The top surface is then cemented to a piece of glass, usually Canada balsam and the remainder of the material is ground away until only a thin film remains which in the best rock sections is not over one mm. in thickness. The section is finally embedded in balsam, usually 1.54 and over it a thin cover glass is laid. In the preparation of a section the surfaces are not polished hence from the nature of the abrasive they must be pitted and scratched and it may be assumed that in cross section such a preparation would be somewhat as represented in fig. 544 D. When a thin section is examined under the microscope the light enters the section from below, having been reflected into the microscope tube by an inclined mirror. Before it reaches the section it will have passed through a Nicol prism and through a slightly convergent lens. Let it be assumed that the mineral in fig. 544 D is made of glass of refractive index. The convergent light entering the section will pass with little or no refraction from the mineral into the balsam because their refractive indices are nearly alike. Hence the roughness of the surface of the section is not

apparent and the mineral appears as if polished. If there is a crack, as at *b*, so much light penetrates that it is scarcely visible when the convergent axis is close to the object, but when the latter is lowered, and especially when the light is restricted by the use of an iris diaphragm inserted into the microscope, the nearly parallel rays of light will suffer some total reflection along the line of the crack and so make it visible. On the other hand, if the material has a high index of refraction there will be innumerable pinpoints over the section where the surfaces are so inclined, but the light will suffer total reflection in attempting to pass from the optically dense mineral into the rarer medium. Hence, the uneven surfaces of the section due to its grinding apparently vanish. This effect is more pronounced if the convergent axis is lowered. The cracks, too, may exist in a mineral of high index of refraction parallel to the surface, as in the case of quartz, but not in a mineral of low index. Further, if minerals of high index of refraction are polished in one of two ways (Fig. 644 *D*) there will be places along the outer edge where total reflection will take place, thus causing a surface to be dark and lustrous. This effect combined with the rounded aspect of the surface and the apparent increase in thickness as described in the preceding paragraph will tend to make a mineral of high index of refraction stand out conspicuously in relief. These effects are greatly best with a microscope of high power, or a microscope above with the condenser lens lowered, and the background darker.

330. Determination of the Indices of Refraction of Mineral Grains under the Microscope.—The conclusions of the preceding article suggest a means of determining the indices of refraction of mineral grains under the microscope. If a grain is immersed in a liquid of known index of refraction it is possible to determine whether it has a higher or lower index of refraction than the liquid and by the use of a series of liquids of varying refractive indices it is possible to determine with considerable accuracy the index of refraction of the mineral. A list of liquids* commonly used for such purposes, with their indices of refraction is given below.

Petroleum distillates.....	1.45-1.457
Mixtures of refined petroleum oils and turpentine.....	1.450-1.475
Carbon tetrachloride, carbon disulfide, or chloroform.....	1.480-1.535
Chloroform and carbon tetrachloride and carbon disulfide.....	1.490-1.635
Perchloroethylene and carbon tetrachloride.....	1.475-1.650
Carbon tetrachloride, bromine and perchloroethylene.....	1.650-1.740
Sugar, less water, and xylene.....	1.740-1.760
Mixtures of methylene iodide with alcohol of arbitrary, anisole, and carbon tetrachloride (see above).....	1.740-1.870
Methylene iodide and carbon tetrachloride (see above).....	1.740-2.280
Resinous substances formed from benzene, turpentine and methylene iodide, carbon tetrachloride.....	1.680-2.100
Mixtures of the chloride, bromide and iodide of thallium (see Barth).....	2.24-2.78

* Wright, *Methods of Petrographic Microscopy*, p. 28. American Jour. Wash. Acad. Sci., 3, 1, 1, 1909. *Min. Mag. Soc. London*, 1912, 1913, 1914, 1915, 1916, 1917, 1918, 1919, 1920, 1921, 1922, 1923, 1924, 1925, 1926, 1927, 1928, 1929, 1930, 1931, 1932, 1933, 1934, 1935, 1936, 1937, 1938, 1939, 1940, 1941, 1942, 1943, 1944, 1945, 1946, 1947, 1948, 1949, 1950, 1951, 1952, 1953, 1954, 1955, 1956, 1957, 1958, 1959, 1960, 1961, 1962, 1963, 1964, 1965, 1966, 1967, 1968, 1969, 1970, 1971, 1972, 1973, 1974, 1975, 1976, 1977, 1978, 1979, 1980, 1981, 1982, 1983, 1984, 1985, 1986, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020, 2021, 2022, 2023, 2024, 2025, 2026, 2027, 2028, 2029, 2030, 2031, 2032, 2033, 2034, 2035, 2036, 2037, 2038, 2039, 2040, 2041, 2042, 2043, 2044, 2045, 2046, 2047, 2048, 2049, 2050, 2051, 2052, 2053, 2054, 2055, 2056, 2057, 2058, 2059, 2060, 2061, 2062, 2063, 2064, 2065, 2066, 2067, 2068, 2069, 2070, 2071, 2072, 2073, 2074, 2075, 2076, 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3737, 3738, 3739, 3740, 3741, 3742, 3743, 3744, 3745, 3746, 3747, 3748, 3749, 3750, 3751, 3752, 3753, 3754, 3755, 3756, 3757, 3758, 3759, 3760, 3761, 3762, 3763, 3764, 3765, 3766, 3767, 3768, 3769, 3770, 3771, 3772, 3773, 3774

The indices of refraction of the test liquids can be determined either by the use of the total refractometer or by filling a hollow glass prism with the liquid and using the methods employed with ordinary mineral prisms, see Art 332.

A series of these liquids should be prepared which for most purposes might conveniently show differences in the indices of the different liquids of 0.01. For more exacting work smaller differences between the indices of the members of the series would be of advantage. If these are kept in well stoppered bottles and are protected from the light they will show very little change over considerable periods of time. It is advisable, however, to check their indices at least once a year.

The mineral to be studied should be broken down in a uniform small grains 0.05 mm. is usually a good diameter, and then a few grains placed upon a glass slide. A drop of liquid with a known index of refraction is then placed upon the grains and the whole covered with a thin cover glass. When a mineral grain is immersed in a liquid of closely the same

index of refraction it loses its sharpness of outline and if the mineral is colorless and the correspondence of the two indices exact it will quite disappear. Certain tests, however, are commonly used to determine the relative indices of the mineral and the liquid which with proper care can distinguish differences as small as 0.01 or with practice and especial care as small as 0.001. To make these tests the condenser below the microscope stage should be lowered so that if the preparation has a sub-stage microscope lens should be partly closed. Under these conditions the collection of the light is reduced and only a small pencil of light composed of nearly parallel rays enters the section. Such mineral grains will usually be thinner in their centers and not somewhat like lenses in their effect upon light. See Fig. 543 represent a mineral grain illuminated in this way when immersed in a liquid of higher index of refraction. The light-rays as they pass from the mineral into the higher refracting liquid above will be bent away from the perpendicular. In the opposite case Fig. 544 where the mineral has the higher index the reverse will be true and the light-rays will be bent toward the perpendicular. This will produce in one case a brighter illumination of the borders of the mineral grain and in the other a brighter illumination of its center. This difference in illumination is, however, commonly so slight as to be certainly detected only with difficulty. The so-called Becke Test is commonly used under these circumstances. This consists in focusing upon the grain with a high power objective and then slowly raising or lowering the microscope tube. The condenser lens beneath the microscope stage should be lowered so that

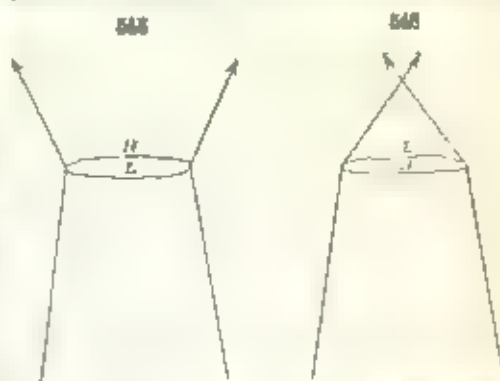
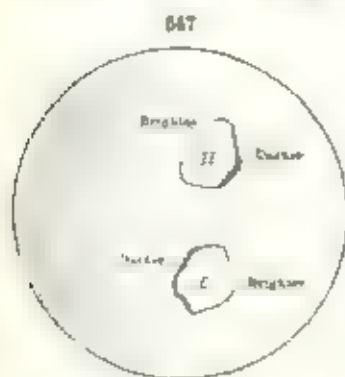


Fig. 543. Grain with Low Refractive Index in a High Refractive Index Liquid. Fig. 544. Grain with High Refractive Index in a Low Refractive Index Liquid.

as 0.001. To make these tests the condenser below the microscope stage should be lowered so that if the preparation has a sub-stage microscope lens should be partly closed. Under these conditions the collection of the light is reduced and only a small pencil of light composed of nearly parallel rays enters the section. Such mineral grains will usually be thinner in their centers and not somewhat like lenses in their effect upon light. See Fig. 543 represent a mineral grain illuminated in this way when immersed in a liquid of higher index of refraction. The light-rays as they pass from the mineral into the higher refracting liquid above will be bent away from the perpendicular. In the opposite case Fig. 544 where the mineral has the higher index the reverse will be true and the light-rays will be bent toward the perpendicular. This will produce in one case a brighter illumination of the borders of the mineral grain and in the other a brighter illumination of its center. This difference in illumination is, however, commonly so slight as to be certainly detected only with difficulty. The so-called Becke Test is commonly used under these circumstances. This consists in focusing upon the grain with a high power objective and then slowly raising or lowering the microscope tube. The condenser lens beneath the microscope stage should be lowered so that

the grains under observation be above its focal point. In the case illustrated by Fig. 545 when the tube is raised, a narrow line of light will be seen to move outward from the mineral, while when the tube is lowered this line will move inward. In the case illustrated in Fig. 546 the opposite conditions will prevail. A convenient rule to remember is that when the microscope tube is raised the Becke line will move toward the material of higher refractive index and when the tube is lowered this line will move toward the material of lower index. This makes a very satisfactory and quite delicate test for distinguishing differences in refractive indices. Sometimes two lines will appear moving in opposite directions and it may be difficult to decide which is the Becke line. This is usually corrected by lowering the condenser or decreasing the aperture in the iris diaphragm. For the use of the Becke test in rock sections, see Art. 331.

The test upon mineral grains immersed in a liquid may also be made by means of oblique illumination. An oblique pencil of rays may be obtained



presented in Fig. 547 where *L* and *H* represent grains with indices respectively lower and higher than the liquid in which they are immersed. If the condenser lens is raised so that the mineral grain will be below its focus, effects exactly opposite to those described above will be noted. It is wise to test the apparatus used by observing mineral fragments of known indices and taking note of the effects produced.

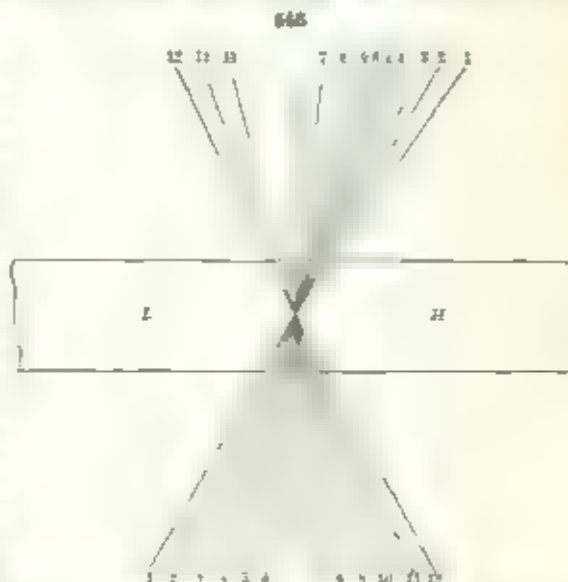
Obviously the liquid used must have a higher dispersion than the mineral to be tested. In other words the liquid will have distinctly different indices of refraction for red and for blue light. If the mineral should have an index intermediate between those for red and blue light in the liquid, the grain when illuminated in oblique light will show colored borders. With the condenser lens lowered the edge of the mineral next to the shadow will be colored an orange-red while the edge away from the shadow will be pale blue. If the amount of dispersion in the liquid is not too great this effect gives very closely the refractive index of the mineral.

It should be pointed out here that all minerals except those of the isometric system, show different indices of refraction depending upon the crystal direction in which the light is vibrating while passing through the mineral. Consequently uniaxial grains of a mineral, unless it belongs to the isometric

system will show a variation in the refractive indices depending upon their position on the slide. Sometimes it is possible to ascertain the crystal orientation of a grain due to some significant cleavage or structure and so through the index of some particular crystal direction but ordinarily so that can be determined by the mean index of refraction of the mineral.

331. The Becke Test in Rock Sections. The Becke test can be often used in a rock section to determine the relative indices of refraction of two different minerals lying in contact with each other. Their contact plane should be nearly vertical in order to give clear results. The position of this plane can be determined

by focusing on the surface of the section and then viewing in microscope (be it lowered, but whether or not the position of the dividing line between the two minerals remains stationary or moves. If it remains stationary or moves only a little the dividing plane is vertical or nearly so. Under these conditions assume that the cone of light entering from below is focused at point *a*, Fig. 518, lying on the dividing plane between *L* mineral with lower index and *H* mineral with higher index. The light rays *b* & *c* passing as they do from a mineral of lower index



of higher will suffer no total reflection and all emerge from the section on the side of *H*. On the other hand, rays 7 & 12 attempting to pass from *H* to *L* will only in part pass across the dividing plane while the others will be totally reflected and show themselves as rays 1 on the side of *H*. *H* will therefore show a brighter illumination than *L*. In the use also when the tube of the microscope is raised the Becke line will be seen moving toward the mineral of higher index or when the tube is lowered, toward that of lower index. The test results will be obtained by using an objective of high light heat and a condenser lens must be inverted.

332. Dispersion Methods. Various methods have been devised for the determination of indices of refraction with the microscope which depend upon the ability to vary the index of a medium by a variation in the wavelength of the light or by a change in temperature. By this means it is possible to vary the index of the liquid until it exactly matches that of the mineral grain. It is possible to make determinations that are accurate to .001. The disadvantages of the methods are that they require more apparatus and greater skill in manipulation.

By using a monochromatic illuminator, the index of a given mineral may

be determined for a certain wave-length of light when immersed in a certain liquid. The index of refraction of that particular liquid for several wave-lengths of light being already known it is possible to establish the index of refraction of the mineral for the wave-length of sodium light. In practice the same mineral could be immersed in two or three different liquids in order to check the results.*

Various is the index of a solid may also be produced by a change in its temperature. A glass through which water of a known temperature can be readily passed on the stage of the microscope and the refractive indices and refractive liquid are passed on the same glass plate that forms the upper surface of the cover. The temperatures of the glass equalized the way be varied until the index of refraction matches that of the mineral. The refractive indices of the mineral as a function of temperature being known for varying temperatures, the index of the mineral can be determined for a given temperature.

A combination of these two methods known as the dispersive dispersion method is the best result.† The refractive index of the liquid decreases as the wave-length of light used increases and also as the temperature of the liquid rises. On the other hand the refractive index of the mineral decreases as the temperature of the liquid and wave-length of light will be so small as to be ordinarily negligible. By choosing liquids that show a maximum light and heat dispersion it is possible to cover the range of refractive indices with only one or two liquids.

333. Determination of the Index of Refraction by Means of Prisms or Plates. For a more accurate determination of the indices of refraction of minerals a more exact prism or plate of the mineral is used. In all cases, except in the case of an isotropic system, the prism or plate uses in at least one certain crystallographic direction. This method however will be discussed where the principal characters of each mineral are given. For the present we will assume that the crystal shows a maximum of birefringence and a minimum of birefringence. There are two chief methods of determining the index of refraction by the use of a prism.

1. The Method of Perpendicular Incidence. This method although not the one most generally employed is an excellent one to use when combined with and may be used to advantage in some cases and from it the formulae necessary for finding the refractive index are readily derived. It is necessary to have a prism of the mineral which has two plane surfaces meeting at a small angle.

This angle should be small enough so that the light may pass freely through the prism and not suffer any total reflection. First let us suppose that the angle of incidence with the rate n where $n = 1.431$ the prism angle must be less than $41-12'$ for total reflection to occur and would take place. For a mineral of higher index the angle would have to be smaller. Thus with diamond $n = 2.417$ where total reflection would take place at $24-34'$. On the other hand more refractive results will be obtained if the prism angle is fairly near to the limit for the mineral being used.

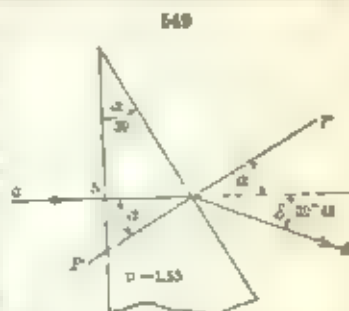
Let Fig. 349 represent the cross section of a small prism. Let a b represent a ray of light striking the face of the prism at 90° incidence. It will suffer

* See *Philosophical Magazine*, J. Am. Chem. Soc. 44, 1922. *London Min. Mag.*, 20, 1923.

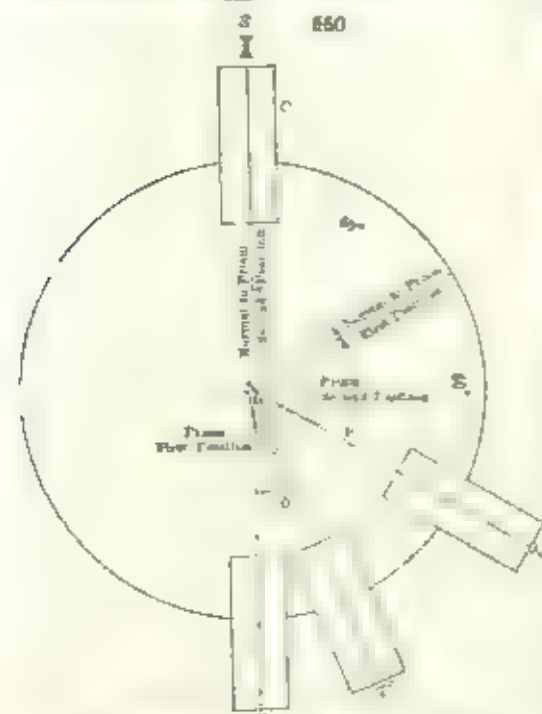
† Esmonts, *Am. Min.*, 13, 504, 1928.

no deviation in its path on entering the prism but will proceed with somewhat diminished velocity until it reaches c . In passing out of the prism at this point, from a denser to a rarer medium, the light will be deflected away from the normal to the surface, $P'P'$, passing a deviation δ in the direction $c-d$. The data necessary for the calculation of the index of refraction under these conditions are the angle of the prism, α , and that of the deviation in the path of the light δ . It is easy to see from the figure that α and α' are equal, for they are both parts of right-angled triangles having the angle $bP'c$ in common, and α' is equal to α because they are opposite angles. The angle of incidence, as defined in Art. 322, is equal to $\alpha + \delta$ and the angle of refraction is equal to α . Therefore

the usual formula $\frac{\sin i}{\sin r} = n$ becomes here $\frac{\sin(\alpha + \delta)}{\sin \alpha} = n$. In order to make



Refraction of Light through a Prism
Method of Legendre used in practice



Determination of Index of Refraction
Method of Perpetua star in practice

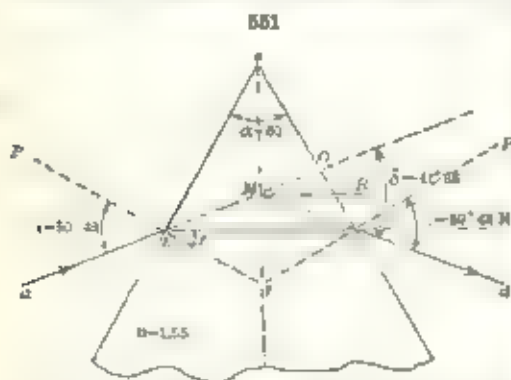
a determination of the index of refraction, therefore, it is necessary to measure these two angles, α and δ .

The prism is mounted on a one-circle reflector goniometer and its angle α measured in the same way as an angle upon a crystal. The instrument is then adapted to the uses of a refractometer. For this purpose it is necessary to note that the telescope and vernier are both fastened to the outer rim of the instrument and move together. The graduated circle being clamped, the telescope tube is first moved to the position T (Fig. 550) so that the rays from the collimator tube C pass at the edge of the prism, cause the light signal to fall on the vertical cross-hair of the telescope. The outer circle being clamped, the telescope is next moved through an arc of exactly 60° to position T'' and then clamped. Next the

prism is turned to the first position so that the light from C is reflected from its right-hand face and the signal falls on the cross-hair of T' . In

this position the normal, N , to the prism face, must bisect the angle between the axes of C and T' . The prism is now turned through an angle of exactly 60° to its second position, which brings the normal N exactly in line with the axis of the collimator tube. When this has been accomplished the graduated circle is securely clamped. The telescope may now be unclamped and moved without altering the position of the prism, and somewhere between T' and T'' a position T''' will be found where the refracted ray falls on the cross-bar of the telescope. The movement of the telescope from the position T' back to T''' gives the angle of deviation or δ , of the light-ray that has been refracted by the prism. In practice it is well to repeat the measurements each of α and δ several times and to go through all the operations of setting the positions of the prism and telescope. If white light is used for illumination the refracted ray seen at T''' will appear as a narrow spectrum. To make an exact determination a monochromatic light (sodium light is best) must be employed.

2. *The Method of Minimum Deviation* — This is the method that is most generally employed for determining indices of refraction by the use of prisms.



It depends upon the principle that when a beam of light, *abcd*, Fig. 551, traverses a prism in such a way that the angles i and i' are equal, the beam suffers the minimum amount of deviation in its path of any possible course through the prism. This fact may be proven empirically by experimentation on the refractometer. In order to make a determination the angle α of the prism is first measured on the goniometer. The angle of the prism, with this method

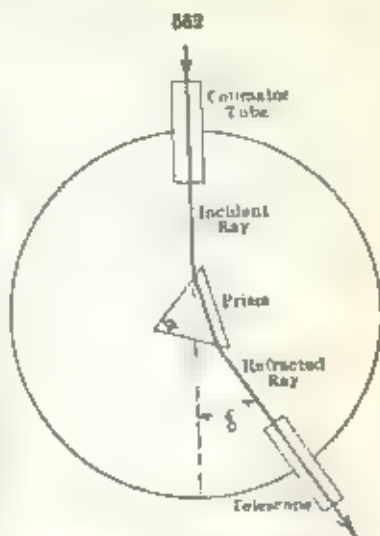
may be considerably larger than when the method of perpendicular incidence is used. The determination will increase in accuracy as the angle of the prism approaches its maximum possible size. The prism is then turned with its edge to the left about, as in the position shown in Fig. 552 the telescope unclamped and moved until the refracted ray appears in it. Now, turn the central post with the prism on it toward the left and follow the signal with the telescope. The position of minimum deviation is soon reached, when, on turning the prism, the signal seems to remain stationary for a moment and then moves away to the right, no matter in which direction the prism is turned. A little practice is needed to determine exactly the position of minimum deviation and the measurement should be made in monochromatic light. When the telescope is properly placed a narrow, graduated circle is clamped and the telescope turned until the direct signal from the collimator tube is fixed upon the vertical cross-bar. The angle between these two positions of the telescope is the same as the angle of deviation, or δ . The formula for making the necessary calculation from these measurements follows very simply from a comparison of Figs. 551 and 549. It may be imagined that Fig. 551 is composed of two prisms like Fig. 548 placed back to

back. This results in doubling the angles α and δ so that the formula now becomes

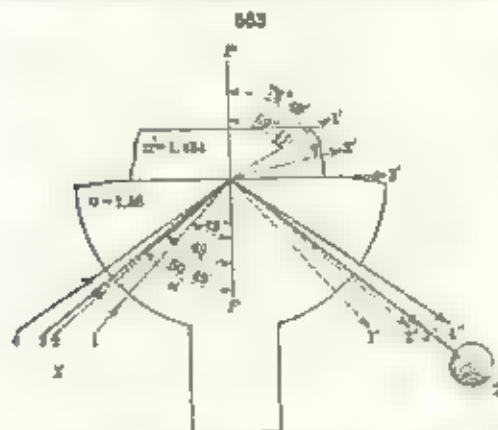
$$n = \frac{\sin \frac{1}{2}(\alpha + \delta)}{\sin \frac{1}{2}\alpha}.$$

3 The Method of Total Reflection —

This method is based upon the principle that light cannot always pass from an optically dense into an optically rarer medium but at a certain angle, known as the critical angle, will suffer total reflection. The critical angle for any substance varies with the index of refraction of that substance as explained in Art 328. Consequently if we can measure this critical angle we can calculate the index of refraction of the substance. This method is particularly useful because the measurement can be made upon a single polished surface, which may be quite small in area. This measurement is made by means of an instrument, known as the Total Refractometer, a description of which will be found in Art 359. The essential feature of this instrument is a hemisphere of glass with a known, high index of refraction. The upper surface of the hemisphere is plane and should be accurately adjusted in a horizontal position. The mineral to be tested may be of any shape provided that some surface upon it has been ground plane and polished. A drop of some liquid of high index of refraction is placed between the surface of the glass hemisphere and the flat surface of the mineral. This serves to unite the two substances and dispel the thin layer of air that would otherwise separate them. The liquid should have an index of refraction intermediate between that of the glass and that of the mineral. As the liquid lies between the two substances in the form of a thin film with parallel surfaces



Determination of Index of Refraction
Method of Minimum Deviation



Determination of Index of Refraction
Method of Total Reflection, I

whatever optical effect it has upon the light as it enters will be balanced by the opposite effect as the light leaves the film. So the presence of the film of liquid can be ignored. Fig. 553 represents a cross section of such a hemisphere with a mineral plate resting upon it. Let it be now supposed that, by

whatever optical effect it has upon the light as it enters will be balanced by the opposite effect as the light leaves the film. So the presence of the film of liquid can be ignored. Fig. 553 represents a cross section of such a hemisphere with a mineral plate resting upon it. Let it be now supposed that, by

334. Dispersion — Thus far the change in direction which light suffers in reflection and refraction has alone been considered. It is further to be noted that the amount of refraction differs for light of different wave-lengths, being greater for blue than for red. In consequence of this fact, if ordinary light be passed, through a prism, as in Fig. 551, it will not only be refracted but will also suffer a dispersion or be separated into its component colors, thus forming the prismatic spectrum.

This variation for the different colors depends directly upon their wave-lengths. The red waves are longer, their transverse vibrations are slower, and it may be shown to follow from this that they suffer less change of velocity on entering the new medium than the violet waves, which are shorter and whose velocity of transverse vibration is greater. Hence the refractive index for a given substance is greater for blue than for red light. The following are values of the refractive indices for diamond as obtained by Schaeff:

2.40846 red (lithium flame),
2.41723 yellow (sodium flame),
2.42549 green (calcium flame).

335. Spectroscopes. The instrument most commonly used for the analysis of the light by dispersion is familiar to us as the spectroscopic telescope. There are a number of varieties of spectroscopes, the simplest of which consists of a glass prism mounted at the center of the instrument, with two tubes pointing away from it. The light from the given source is received through a narrow slit in the end of one tube and made to fall, as a parallel beam, upon one surface of a prism at the center. The light is dispersed by its passage through the prism, and the spectrum produced is viewed through a suitable telescope at the end of the second tube.

If the light from an incandescent solid, which is white (Fig. 319), is viewed through the spectroscopic telescope, the complete band of colors of the spectrum is seen from the red through the orange, yellow, green, blue to the violet. If, however, the light from an incandescent vapor is examined, it is found to give a spectrum consisting of bright lines or bands only, and these in a definite position characteristic of the substance. Thus the yellow line doublet of sodium vapor, the more complex series of lines and bands, red, yellow, and

reaches $i = 90^\circ$ and $\sin i = 1$. There are, as we may remember, and have

$n = \frac{\text{velocity of light in vacuum}}{\text{velocity of light in mineral}}$ or $\text{velocity of light in vacuum} = \frac{1}{n}$. Further, we may derive in the same way for the highly reflecting glass of the hemisphere whose refractive index

n is known, the expression, $\text{velocity of light in glass} = \frac{1}{n}$. Further, we have at the case of the light attempting to pass from the glass (plus a lensed medium) into the mineral the expression $\frac{\text{velocity of light in mineral}}{\text{velocity of light in glass}} = \frac{\sin 90^\circ}{\sin i}$ measured on an instrument. By substituting this becomes

$$\frac{1}{n} = \frac{\sin 90^\circ}{\sin i} = \frac{1}{\sin i}$$

$$\frac{1}{\sin i} = \frac{n'}{n} \text{ or } n = \sin i \times n'.$$

of *seq*), one of the rays always retains its initial direction normal to the surface, but the other except in certain special cases, is in part or was deviated from it. With a biaxial substance, further both rays are usually refracted and bent from their original direction. In the case of both uniaxial, and biaxial media, however it is a fact that the normal to the wave-front remains unrefracted with perpendicular incidence.

340 Interference of Waves in General.—The subject of the interference of light-waves, alluded to in Art 337, requires a detailed discussion. It is one of great importance since it serves to explain many common and beautiful phenomena in the optical study of crystals.

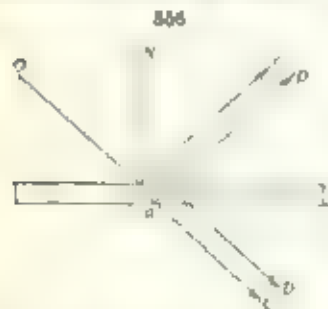
Referring again to the water-waves spoken of in Art 313, it is easily understood that when two wave-systems going on in a straight line from two centers of disturbance meet one another, come together if at a given point they meet in the same phase (as crest to crest) the result is to give the particles a question of double amplitude of motion. On the other hand if at any point the two wave-systems come together in opposite phases that is to say a wave-length apart, the crest of one corresponding to the trough of the other, they interfere and the amplitude of motion is zero. Under certain conditions, therefore, two sets of waves may mutually destroy each other completely, and on the other hand they may mutually increase and destroy each other. Thus, in a number of cases of interference between these systems. What is true of the waves mentioned is true also of sound-waves, and of waves in motion in general. A very simple case of interference was spoken of in connection with the sound of the waves carried by a string (p. Art 315).

341. Interference of Light-waves. Interference phenomena may be more satisfactorily studied in the case of light-waves. The experiments are not few. If two waves of like length and intensity, and propagated in the same direction meet in the same phase they unite to form a wave of double intensity and amplitude. This, as stated in Art 316, will cause an increase in the intensity of the light. If a wave and the waves differ in phase by half a wave-length, or in other words, by half a cycle of vibration, they mutually extinguish each other and no light results. For other relations of phase, say in the case of interference forming a new resultant wave, differing in amplitude from each of the component waves. In the above cases, considered in light-waves

were assumed that is, those of the longest. If ordinary white light is used interference for certain wave-lengths may result with the consequent subtraction of the corresponding color from the white light and so give rise to various spectral colors.

342 Illustrations of Interference.—A simple illustration is afforded by the bright colors of very thin films of plates. A film of oil on water, a soap bubble, and the cause. To understand these it is only necessary to remember that the incident light waves are reflected in part from the upper and in part

from the lower surface of the film or plate. The rays that are reflected from the under surface of the very thin film (see Fig 550) having traveled a greater distance and with a different velocity will, when they unite with those rays reflected from the upper surface, show in general a different phase. For



some particular wave-length of light this difference is likely to be exactly a half wave-length or some odd multiple of this amount and so the corresponding color will be eliminated. Assuming but ordinary white light in being used, and its complementary color will be seen. It is to be noted that the phenomena of interference by reflection are somewhat complicated by the fact that there is a reversal of phase (that is a loss of half a wave-length) at the surface that separates the medium of greater optical density from the rarer one. Hence the actual relative phase of the two reflected rays as to *III*, supposing them of the same wave-length, is not determined by the retardation in the greater length path traversed, by *BD* together with the loss of a half wave-length at *C*, the reversal of phase spoken of. As shown in the figure there are also two transmitted waves which also interfere in like manner.

A plano-convex lens of long curvature resting on a plane glass surface (Fig. 557) and hence separated from it except at the center by a film of air of varying thickness gives by reflected light a series of light and dark rings called Newton's rings. The mark at *C* in the figure is the interference of the incident and reflected waves the latter with a wave-length behind the former.

557



The light rings correspond to the divisions where the two sets of reflected waves are in the same phase that is, where the expansion always where the reflection of those having the longer path is half a wave-length or an odd multiple of this, $\frac{1}{2}\lambda$, $\frac{3}{2}\lambda$, etc. So also the dark rings fall between these and correspond to the points where the two waves meet in opposite phase, the retardation being a wave-length or an odd multiple of this. The rings are denser together with those toward the center, so that the air film has a thickness of $\frac{1}{2}\lambda$ at the light. In each of the cases described the ring is properly the intersection on the plane surface of the circle of radius $\sqrt{\lambda x}$ and $\sqrt{\lambda y}$.

If ordinary white light were used instead of the monochromatic and dark rings described above, a series of colored bands. If the center of the lens were slightly raised, the light from the points of the dark rings indicates white light for that particular wave-length has been extinguished by bright interference. White light is used for convenience in respect to its component having the various visible light wave-length have not changed and the light will all be extinguished at the same points. At now instead of dark rings we get rings having the complementary color blue. If our original illustration was by yellow light, the dark rings would have had a different complementary color, green, instead of blue. And again when white light is used red light is extinguished at those points and its complementary color shows. In this way we obtain a series of colored rings each showing the successive colors of the spectrum. The series of the spectrum colors are repeated a number of times due to successive interferences produced by differences of phase of $\frac{1}{2}\lambda$, $\frac{3}{2}\lambda$, $\frac{5}{2}\lambda$, etc. wave-lengths. The different series are distinguished as of the first, second, third, etc., order, for a given color may be repeated a number of times.

The interference rings for different colored lights are not evenly spaced, the rings shown in the figure being for instance closer together than for red. Consequently after three or four repetitions of the spectrum bands the different interference rings begin to overlap one another and the resulting colors become fainter and less pure. Ultimately this overlapping becomes

the higher orders, is shown.

1. $\frac{1}{2} \times \frac{1}{2} = \frac{1}{4}$ (Probability of getting 2 heads)

$$\frac{d}{dt} \left(\int_{\Omega} u^2 dx + \int_{\Gamma} u^2 dS \right) = -2 \int_{\Omega} u \Delta u dx - 2 \int_{\Gamma} u \nabla_n u dS = -2 \int_{\Omega} |\nabla u|^2 dx - 2 \int_{\Gamma} | \nabla_T u |^2 dS \leq 0.$$

349. Polarization and Polarized Light — (5017) 15 1911 18 1912 19 1913 20 1914 21 1915 22 1916 23 1917 24 1918 25 1919 26 1920 27 1921 28 1922 29 1923 30 1924 31 1925 32 1926 33 1927 34 1928 35 1929 36 1930 37 1931 38 1932 39 1933 40 1934 41 1935 42 1936 43 1937 44 1938 45 1939 46 1940 47 1941 48 1942 49 1943 50 1944 51 1945 52 1946 53 1947 54 1948 55 1949 56 1950 57 1951 58 1952 59 1953 60 1954 61 1955 62 1956 63 1957 64 1958 65 1959 66 1960 67 1961 68 1962 69 1963 70 1964 71 1965 72 1966 73 1967 74 1968 75 1969 76 1970 77 1971 78 1972 79 1973 80 1974 81 1975 82 1976 83 1977 84 1978 85 1979 86 1980 87 1981 88 1982 89 1983 90 1984 91 1985 92 1986 93 1987 94 1988 95 1989 96 1990 97 1991 98 1992 99 1993 100 1994 101 1995 102 1996 103 1997 104 1998 105 1999 106 2000 107 2001 108 2002 109 2003 110 2004 111 2005 112 2006 113 2007 114 2008 115 2009 116 2010 117 2011 118 2012 119 2013 120 2014 121 2015 122 2016 123 2017 124 2018 125 2019 126 2020 127 2021 128 2022 129 2023 130 2024 131 2025 132 2026 133 2027 134 2028 135 2029 136 2030 137 2031 138 2032 139 2033 140 2034 141 2035 142 2036 143 2037 144 2038 145 2039 146 2040 147 2041 148 2042 149 2043 150 2044 151 2045 152 2046 153 2047 154 2048 155 2049 156 2050 157 2051 158 2052 159 2053 160 2054 161 2055 162 2056 163 2057 164 2058 165 2059 166 2060 167 2061 168 2062 169 2063 170 2064 171 2065 172 2066 173 2067 174 2068 175 2069 176 2070 177 2071 178 2072 179 2073 180 2074 181 2075 182 2076 183 2077 184 2078 185 2079 186 2080 187 2081 188 2082 189 2083 190 2084 191 2085 192 2086 193 2087 194 2088 195 2089 196 2090 197 2091 198 2092 199 2093 200 2094 201 2095 202 2096 203 2097 204 2098 205 2099 206 2100 207 2101 208 2102 209 2103 210 2104 211 2105 212 2106 213 2107 214 2108 215 2109 216 2110 217 2111 218 2112 219 2113 220 2114 221 2115 222 2116 223 2117 224 2118 225 2119 226 2120 227 2121 228 2122 229 2123 230 2124 231 2125 232 2126 233 2127 234 2128 235 2129 236 2130 237 2131 238 2132 239 2133 240 2134 241 2135 242 2136 243 2137 244 2138 245 2139 246 2140 247 2141 248 2142 249 2143 250 2144 251 2145 252 2146 253 2147 254 2148 255 2149 256 2150 257 2151 258 2152 259 2153 260 2154 261 2155 262 2156 263 2157 264 2158 265 2159 266 2160 267 2161 268 2162 269 2163 270 2164 271 2165 272 2166 273 2167 274 2168 275 2169 276 2170 277 2171 278 2172 279 2173 280 2174 281 2175 282 2176 283 2177 284 2178 285 2179 286 2180 287 2181 288 2182 289 2183 290 2184 291 2185 292 2186 293 2187 294 2188 295 2189 296 2190 297 2191 298 2192 299 2193 300 2194 301 2195 302 2196 303 2197 304 2198 305 2199 306 2200 307 2201 308 2202 309 2203 310 2204 311 2205 312 2206 313 2207 314 2208 315 2209 316 2210 317 2211 318 2212 319 2213 320 2214 321 2215 322 2216 323 2217 324 2218 325 2219 326 2220 327 2221 328 2222 329 2223 330 2224 331 2225 332 2226 333 2227 334 2228 335 2229 336 2230 337 2231 338 2232 339 2233 340 2234 341 2235 342 2236 343 2237 344 2238 345 2239 346 2240 347 2241 348 2242 349 2243 350 2244 351 2245 352 2246 353 2247 354 2248 355 2249 356 2250 357 2251 358 2252 359 2253 360 2254 361 2255 362 2256 363 2257 364 2258 365 2259 366 2260 367 2261 368 2262 369 2263 370 2264 371 2265 372 2266 373 2267 374 2268 375 2269 376 2270 377 2271 378 2272 379 2273 380 2274 381 2275 382 2276 383 2277 384 2278 385 2279 386 2280 387 2281 388 2282 389 2283 390 2284 391 2285 392 2286 393 2287 394 2288 395 2289 396 2290 397 2291 398 2292 399 2293 400 2294 401 2295 402 2296 403 2297 404 2298 405 2299 406 2300 407 2301 408 2302 409 2303 410 2304 411 2305 412 2306 413 2307 414 2308 415 2309 416 2310 417 2311 418 2312 419 2313 420 2314 421 2315 422 2316 423 2317 424 2318 425 2319 426 2320 427 2321 428 2322 429 2323 430 2324 431 2325 432 2326 433 2327 434 2328 435 2329 436 2330 437 2331 438 2332 439 2333 440 2334 441 2335 442 2336 443 2337 444 2338 445 2339 446 2340 447 2341 448 2342 449 2343 450 2344 451 2345 452 2346 453 2347 454 2348 455 2349 456 2350 457 2351 458 2352 459 2353 460 2354 461 2355 462 2356 463 2357 464 2358 465 2359 466 2360 467 2361 468 2362 469 2363 470 2364 471 2365 472 2366 473 2367 474 2368 475 2369 476 2370 477 2371 478 2372 479

[illegible]

proposed by the Commission. The Commission has also been asked to consider the possibility of a new type of "special" or "limited" license, which would be issued to a person who has been convicted of a crime and is seeking to re-enter the country. The Commission has also been asked to consider the possibility of a new type of "conditional" or "probationary" license, which would be issued to a person who has been convicted of a crime and is seeking to re-enter the country. The Commission has also been asked to consider the possibility of a new type of "restricted" or "limited" license, which would be issued to a person who has been convicted of a crime and is seeking to re-enter the country.

... by reflection and by single refraction.

344. Polarization by Reflection and Single Refraction. In general,

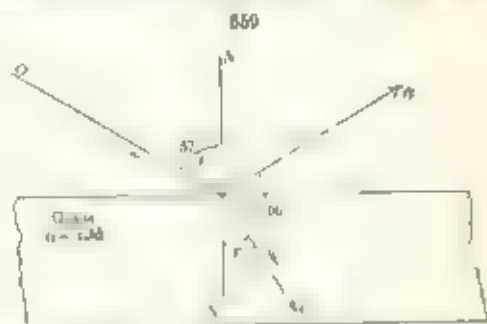
Fig. 1. The effect of the concentration of the solution of the initiator on the rate of polymerization of styrene in the presence of the initiator and the inhibitor.

[illegible]

of the responsibility of the agent

from a polished and transparent surface is not completely polarized but there is an angle of incidence for every substance at which the amount of polarization is the maximum. This will happen, as illustrated in Fig. 343, when the angle between the reflected and refracted rays AB and AC equals 90° . It is evident from a consideration of the figure that the angle r is the complement of i , hence the formula $\frac{\sin i}{\sin r} = n$ becomes in this case

$$\frac{\sin i}{\cos i} = \tan i = n.$$



Brewster's Law.

This law, established by Brewster, may be stated as follows:

The angle of incidence for maximum polarization is that angle whose tangent is the index of refraction of the reflecting substance.

For crown glass this angle is about 57° (see Fig. 343). If light suffers repeated reflections from a series of thin glass plates the polarization is made complete though its intensity is weakened. Metallic surfaces polarize light very slightly.

345. Polarization by Double Refraction. When light is passing through a crystal the motion is doubly refracted. Art. 338, it is noted that a ray of white light is analyzed into that which is completely polarized and that none at right angles to each other. This property can only be satisfactorily explained after a full discussion of the properties of anisotropic crystals. Here, however, it may be alluded to here since this principle gives the most satisfactory method of obtaining polarized light. For this also it is necessary that one of the two waves systems should be extinguished so that only one could be to a high degree of polarization is transmitted. This is accomplished by transmission and absorption in the case of tourmaline plates and by artificial means in the case of calcite.

346. Polarized Light by Absorption. Light passing through a strongly colored tourmaline crystal in the section of a tourmaline crystal, the section being cut parallel to the vertical crystallographic axis, will be almost completely polarized. This can be easily demonstrated in the following way: Select a polished tourmaline surface or a glass top and set it in such a position that light from a window is reflected from the polished wood on the eye. Look at this reflected light through the tourmaline section holding it first with the direction of the crystal axis in a horizontal position and then turning the section until the axis becomes vertical. The light passing out the tourmaline section is in a condition of partial polarization. If light is reflected from the wood surface and possesses a horizontal vibration direction, it will be noted that when the crystal axis of the tourmaline is parallel to the section cut by transmitted light but when this axis is vertical the section becomes practically opaque. The crystal structure of the tourmaline is such that light entering it is broken up into two rays, one polarized, refracted, one of which has its vibrations parallel to the c axis, while the vibrations of the other lie in the plane of the horizontal crystal axes. From the foregoing experiment it is

obvious that the light vibrating parallel to the c axis is readily transmitted by the crystal but that the other ray vibrating in the horizontal ab plane, is almost completely absorbed. Under these conditions it is clear that the transmitted light belongs almost wholly to one ray, the vibrant one of which takes place in a single direction. In other words, the light transmitted by such a transparent section is polarized.

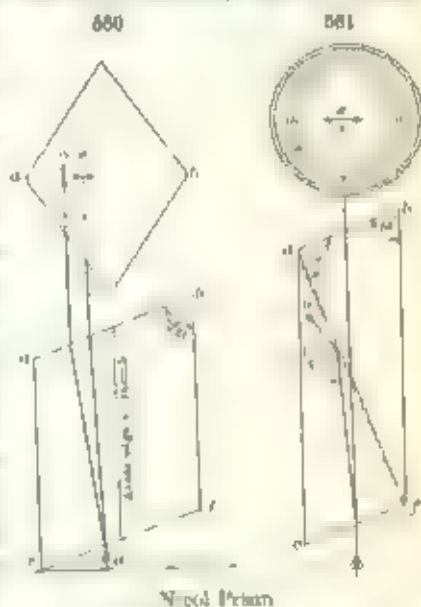
If such sections of *Calcite* are available it is instructive to make the following experiment with them. Place them together, first with their c axes parallel to each other and then turn one section upon the other until these axes are at right angles to each other. In the first case, the light comes through the sections because the c axes of the transmitted rays in the two sections are parallel to each other. In the second case, all light is cut off because now these two vibratory planes are at right angles to each other, the light that did get through the first section being wholly absorbed in the second.

347 Polarized Light by Double Refraction.—*Calcite*, as already stated in Art 338, possesses in a marked degree the power to doubly refract light. If we take a cleavage block of clear *calcite* (looked upon) and hold it at an angle through it, such as *calcite* or one drawn on a piece of paper, one image will appear double. If we take a card and take out a portion, place the card upon one face of a cleavage of *calcite* and looking through the *calcite*, hold it up against a source of light we will observe two light spots. Now if we look at the same way at light reflected from a polished wooden surface, as described in the preceding article, we will find that when a light object is viewed at an angle to the face of the cleavage block is horizontal and if the object is bright white the other is almost invisible. If we then turn the block so that the line seeing the two images of the rhombic face is horizontal the first image will be the second becomes a light. Remembering that the light reflected from the polished wooden surface is largely polarized with a horizontal vibration and it becomes evident from the experiment that the two rays into which a light is broken up in passing through the *calcite* are polarized and that their planes of vibration are at right angles to each other and respectively perpendicular to the rhombic face of the cleavage block. As the double refraction of *calcite* is strong, it follows that at the distance of refraction of the two rays show considerable differences. This fact is taken advantage of in constructing a prism from *calcite* in such a way as to where one ray of these rays is so only, the other ray cut come through the prism, effecting a polarizing the light and image.

The prism requires to show included the *Acute Prism* simply the need. A full explanation of the *calcite* by means of this prism as there would be required a knowledge of the optical properties of hexagonal systems, but a description may be given of the one of interest as construction and uses. In Fig. 360 is represented a cleavage rhomb of *calcite* with its edges vertical. Let it represent a point of light underneath the rhombic rhombic light coming from it will be broken into two rays whose paths through the rhombic prism are shown by the lines *ac* and *bd*. As shown above, these two rays are polarized with vibration directions as indicated by the curved arrows in the top view in Fig. 360. In the construction of a Nicol, the top and bottom surfaces of such a cleavage rhombic prism are ground and polished so that they make angles of 68° with the vertical edges. Then the block is cut in two along the diagonal *ad*, as shown in Fig. 361. These

two surfaces, after being polished, are cemented together by means of a thin layer of Canada balsam. Let us assume that a ray of light enters the prism from below, as shown in Fig. 581. It is broken up into the rays a and e . The ray a travels with the slower velocity, has therefore the higher index of refraction, and shows a greater deviation from the original path. The Canada balsam has a lower index of refraction than ray e which, therefore, when it strikes the layer of balsam, is refracting so pass from an optically dense into a rarer medium. The construction of the prism is such that this ray meets the layer of balsam at an angle greater than the critical angle for this optical combination and suffers, therefore, by reflection, toward the side of the prism and will be absorbed by whatever fastening holds the need.

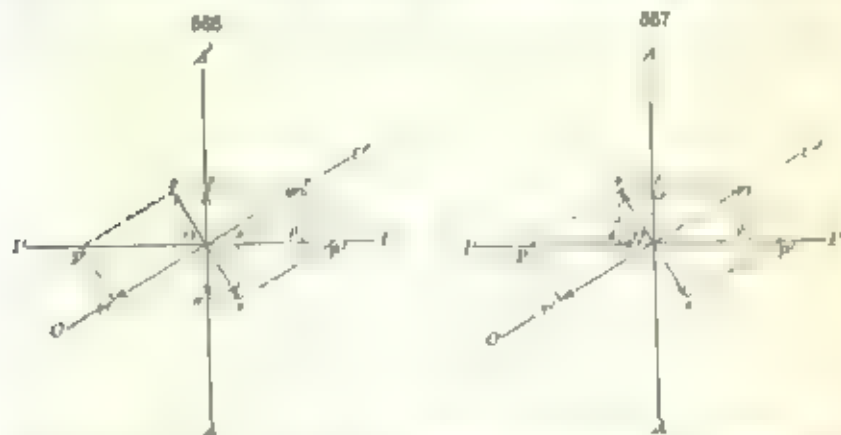
The second ray e passes through the prism with almost no deviation from its original course. Its index of refraction and that of the Canada balsam are nearly the same. Hence the ray suffers almost no lateral shift at the point and passes out of the upper face of the prism. The light, in fact, emerges from a need belonging to the ordinary ray, and is very bright, parallel to the shorter diagonal of the rectangular surface. It should be noted, however, that some prisms are made in a different way and that the above statements are concerning the plane of vibration of the light emerging from the prism (ray e) always hold true. It is always well to test the plane of vibration of a need by looking through it at the floor or a table top as previously described. The prism will show bright when its plane of vibration is horizontal, thus corresponding to the plane of vibration of the refracted light.



348. Polariscopes. Polarizer. Analyzer.—The combination of two prisms, or other polarizing substances, between which transparent material substances may be examined in polarized light, are called, in general, a *polariscope*, the combination formed of which are described later. In any polariscope, the lower prism, or other construction, which polarizes the light given from the examined source is called the *polarizer*; the upper prism is the *analyzer*. If these prisms have their vibration-planes at right angles to each other, they are said to be *crossed*; the incident light polarized by the polarizer will then be extinguished by the analyzer. Strictly, under these conditions it is said to suffer *extinction*.

349. Interference of Plane-polarized Waves. Interference Colors.—When sections of doubly refracting materials are examined in polarized light certain interference effects are continuously obtained that are of great importance. As shown in Art. 347, calcite when it doubly refracts is also polarizes the two rays and in planes that are at right angles to each other. In general, this is true of sections of doubly refracting materials. Consider, then, what takes place when a general section of a doubly refracting material is

sented by $O\tau$ and $O\sigma$ are determined by the parallelogram of forces, as indicated by the dotted lines in the figure. During the passage of these two rays through the quartz the one whose vibrations are represented by $\sigma\sigma'$ travels the faster and it is assumed that the thickness of the quartz wedge at the place under consideration is such that on emerging this ray is just one wave-length ahead of the one whose vibrations are parallel to $\tau\tau'$. Now, when one ray is exactly one wave-length ahead of another, σ may be two, three or any exact number of wave-lengths the conditions are such that, at the first be of the vibration, when an other particle of the ray $\sigma\sigma'$ is just starting from O to σ an other particle of the ray $\tau\tau'$ will be just starting from O to τ . Now consider the effects produced by the same disturbance impacts in the directions O to σ and O to τ upon the other particles of the rays constituting the analyzer



A vibration from σ' to σ acting at O will displace the other particles of the rays to σ and σ' . Likewise a vibration from τ' to τ acting at O will displace the other particles to τ and τ' . Two of these resulting disturbances, namely $O\sigma'$ and $O\tau'$, are easily disposed of (for being in the plane $P-P'$) their effects cannot pass beyond the layer of Canada balsam in the Nicol. The other disturbances $O\sigma$ and $O\tau$ are both in the plane $A-A'$ and can emerge from the Nicol, but since the other particles at O are acted upon simultaneously by forces of equal magnitude acting in opposite directions no disturbance can take place and under these conditions the sector is dark. From the above it follows that, when a section of a doubly refracting material is observed between crossed nicols with its vibration planes making some oblique angle with the vibration planes of the nicols, complete interference will take place for some particular wave-length of light whenever the two polarized rays corresponding to this color emerge from the sector in the same plane.

It is well to consider next the effects that result when, with the planes of vibration of the nicols crossed, light travels through such thicknesses of the quartz wedge that one ray gains $\frac{1}{2}$, or some other half wave-length over the second ray. Let it be supposed, Fig. 567, that at O , the middle of an oscillation from p to p' , the impact is communicated to the other particles. If a quartz section the vertical crystal axis of which lies parallel to the direction $C-C'$. There will result two disturbances in the quartz, one from O to τ and

the color can be told in the same way as upon the quartz wedge itself. If such a wedge cannot be found, the quartz wedge is used as described below.

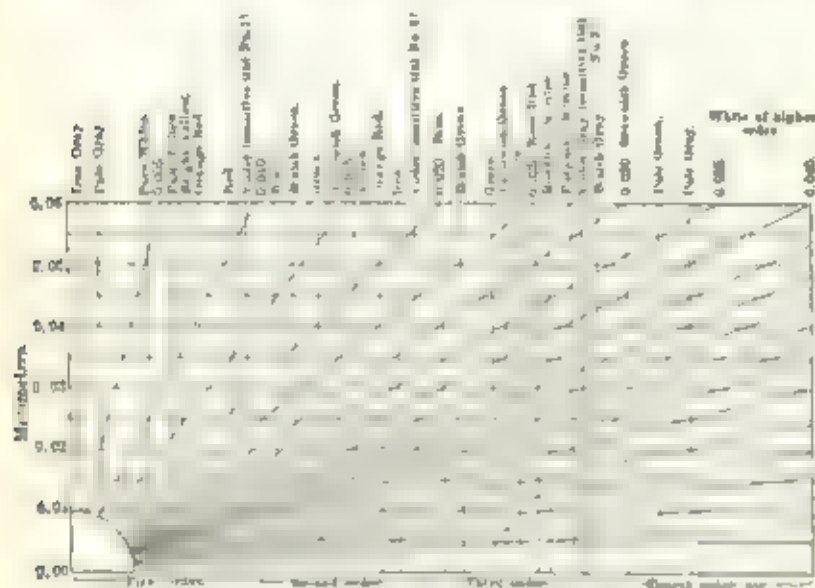
Suppose a colored mineral section is placed upon a reference color of orange-red and is viewed by a microscope in which the light is arranged to be first of second order. Then the microscope will express its field a position of extinction of the section and this can be taken on stage of the microscope (found on image 145). By turning this stage in any one of its sections are brought to such a position that they make angles of 45° with the vertical direction of the polarizer and analyzer. Then insert above the section and below the analyzer a quartz wedge. The optical effect will be what is known. The amount of the wedge should always be inserted first. A dot running through the microscope will give the comparative and making a angle of 45° the wedge here is provided for its purpose.

Under these conditions there are two possibilities. Either the optical effect of the section and the quartz wedge gives the λ direction of section, a part of the λ direction of the wedge, or these two directions are at right angles to each other. The effect of the quartz wedge of the wedge is the section with a color that is a decrease in the amount of color reflection of the light. The numerical value of the color reflection is decreased. The optical effect will be a color that has been increased and in the case of a mineral section which is a section. In the other hand, if the optical effect of the light is increased by the insertion of the quartz wedge, the effect will be as if the section had been turned into the interference color with the light. In the first case the red in order of color. The section will be changed as the wedge is pushed in. The section will be green. In the second case it will change to orange, then to yellow and green. Arrange the section, in order so that upon the section of the quartz wedge the interference colors will fall in its order. Then push the section to push the wedge, noting the successive colors that occur as the amount of λ is increased. Finally the point will be reached where the λ of the wedge will give practically the same amount of color reflection as the mineral section. The two having approximately the same value will be to estimate all interferences and a gray color of the order will result. When this condition rises the quartz wedge is used to compare the mineral by turning the successive colors that occurs until this point is reached the order of the original color of the section can be determined.

353. Determination of Strength of Birefringence — The birefringence or amount of double refraction, varies with different minerals. It is expressed numerically by a figure known as the difference between the greatest and least values of refraction. For a given mineral. In the case of calcite, for instance, the index of refraction for one ray is 1.486 and for the other is 1.058. The birefringence of calcite therefore equals 1.72. This is much higher than for most minerals the strength of birefringence of quartz being only .0091. A convenient criterion of the strength of the birefringence of a mineral is to be able to say, in determining the greatest and least values of refraction. An approximate determination, however, can often be made in a thin section under the microscope. The order of the interference color of a section as given in Art. 361, varies with the thickness of the mineral, its crystallographic orientation and the strength of its birefringence. If the first two factors are known the birefringence can be estimated by noting the interference color of

the section. Fig. 571 will aid in this determination. The thickness of the section is shown in the column at the left. The strength of the birefringence is expressed along the top in right-hand side of the figure. Suppose that a given section was 0.03 mm. in thickness and showed an orange-red interference color of the first order. By following the diagonal line that crosses the horizontal line marked 0.03 mm. at a point lying in the middle of the orange-red of the first order it will be seen that the birefringence of the mineral must be about 0.015. This method of determining birefringence is most commonly used in the case of minerals observed in rock sections. In the case of the best

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Determination of the Strength of Birefringence after Fournier and Robinson

rock sections the thickness of the section is usually about 0.03 to 0.04 mm. The thickness of the section can also be judged from the interference color shown by some known mineral like quartz or feldspar which is to be observed in the section. As the strength of the birefringence of a mineral varies with its crystallographic orientation it is necessary always to look over the rock section at least at three orientations that sections of the mineral which show the highest order of interference color. The birefringence of a mineral is always expressed as the maximum difference between the ordinary rays. Consequently with a uniform thickness, each case obtained in a rock section that section of a mineral which shows the highest order of interference color most nearly approaches the proper orientation for the maximum birefringence.

The order of the interference color of a given section is to be determined by the method of compensation as explained in Art. 352. Spinel quartz wedges are made with scales upon them giving the birefringence produced by the varying thicknesses of the wedge. Such a wedge, described by Wright,

consists of a wedge of quartz placed on top of a plate of quartz, the two having opposite optical orientations, i.e., the Z direction in the plate being parallel to the X direction in the wedge. The thickness of the plate is intermediate between the thicknesses of the two ends of the wedge. At the point, therefore, where the thickness of the wedge equals that of the plate, there will be a dark line showing compensation when the combination is placed between crossed nicols. This point is marked zero on the scale engraved on the wedge. When the wedge is placed above a mineral section, this dark line will be displaced by a distance proportional to the birefringence of the mineral. The latter can then be read directly from the scale engraved on the wedge. For a detailed description of the various wedges and compensators used for this purpose the reader must be referred to the special text-books.*

364. Determination of the Relative Optical Character of the Extinction Directions of any Section of a Doubly Refracting Mineral.—It frequently becomes important to determine which of the two rays of light in a doubly refracting mineral is being propagated with the greater or less velocity; in other words, to determine which of the two directions of vibration corresponds to the X and which to the Z direction. Place the given section under the microscope with the nicols crossed. Find a position of extinction and then turn the section through an arc of 45° so that its vibration directions make 45° angle with the planes of vibration of the nicols. If the section in this position shows a strong color or white of the higher order the quartz wedge is used. The optical orientation of the wedge must be known, i.e., which are its X and Z directions. The wedge is then, placed through the slot above the objective lens, the thin end of the wedge being introduced first. The vibrations of the wedge and the section will now coincide and the effect of the gradual introduction of the wedge where the mineral will be to slowly increase or decrease the birefringence due to the section. The result will be to either increase or lower the order of that interference color obtained. If the X directions of the wedge and the section coincide the effect will be additive in character and the color will rise in its order. If the optical directions of the two are opposed to each other the birefringence is decreased and the color will fall. By noting which effect takes place the X and Z directions of the section are determined.

In this use of the quartz wedge the following precaution must be observed. If the section originally showed a color of the first order and the wedge was introduced in the opposed position the effect would be to cause the color to fall rapidly to gray of the first order. The opposed effect of the quartz wedge would then quickly compensate that of the section. From this point on as the quartz wedge is pushed further in, the optical effect of the wedge will increase and more preponderate over that of the section and the interference colors will now appear in ascending order. Under these conditions, if the first effect of the quartz wedge was overlooked, a wrong conclusion would be made. It is always best to repeat the test with the section rotated 90° from the first position. The two results should be of opposite character and so serve to confirm each other.

Frequently a thick section of a mineral will show a tapering edge somewhere which will show bands of color. When the quartz wedge is introduced

* See Johansen, *Manual of Petrographic Methods*, Wright, *The Methods of Petrographic-Microscopic Research*.

above the section these color bands will move either toward the center of the section, or go off toward the edge. When the color bands move up on the section it means that the effect of the quartz wedge is such that a thicker part of the section is now showing the same interference as a thinner part did originally. In other words, the result is as if the section has been thinned. If this is so, then the X and Z directions of the section and the wedge must be opposed to each other. On the other hand if the color bands move off the section it means that a thicker part of the section is showing the same interference effect that a thinner part did originally. The movement of the quartz wedge has in effect thickened the section and it is in the same or optical directions of the two crystals. This test is particularly useful for determining the X and Z directions of a deeply etched surface as the lateral color of the natural rays over the thicker portions of the section, completely mask the interference color.

If a mineral section shows an interference color of white or gray of the first order the sensitive tint will give better results than the quartz wedge. If no similar optical directions to the section can be seen in the mineral the effect will be to raise the color of the sensitive tint red of the first order to white. On the other hand if the optical directions of the two are opposed the color will fade to gray. This test can be used to advantage only when the birefringent effect of the section is small enough to produce a lower two color of the sensitive tint, respectively blue or yellow.

355. Circularly and Elliptically Polarized Light. In the preceding articles the two interfering light rays were emerging from the mineral crystals were assumed to be polarized in the same plane, for then the resulting phenomena as indicated are comparatively simple. It however the plane polarized rays propagated in the same direction have their vibration directions at right angles to each other and form after one separation of a wavelength, λ , in phase consisting monochromatic rays. These rays be shown that the composition of these rays is equivalent to a beam of circularly polarized light. Briefly expressed this means that a beam of monochromatic light would seem to be propagated by either vibrations being given in cross vibration the line of transmission. From the same or lower vibration would be taken that λ is given, and either vibration is left or right.

If, again, two light rays meet as those described, with a difference of phase differing from λ but not $\frac{\lambda}{2}$, an elliptical vibration of λ can be obtained. Composition gives rise to an elliptical vibration of λ is, a light-ray propagated by elliptical vibrations taking place in cross.

The above result is obtained most simply by passing plane-polarized light through a doubly refracting medium of the proper thickness, e.g., a mica plate which is treated with its vibration plane at right angles to that of the polarizer. If the thickness is such as to give a difference in phase of λ or an odd multiple of this the light which emerges is properly polarized. If the phase differs from λ but is not equal to λ or λ , the emergent light is elliptically polarized.

356. Rotation of Plane of Polarization. In the case of certain doubly refracting crystalline media (as quartz) and some of certain solutions (as of sugar) it can be shown that the light is propagated by two sets of vibrations which take three or four different transverse planes, as in plane polarized light — but in circles, that is each ray is circularly polarized, one being right-handed, the other left-handed. Further of these rays, one will

uniformly gain with reference to the other. The result is that if a ray of plane-polarized light fall upon such a medium assuming the simplest case as a section of quartz cut normal to the vertical crystal axis, it is found that the two rays circularly polarized within have the effect of giving to a plane-polarized ray, but the plane of polarization has suffered an apparent change or rotation, which may be either to the right, to the left, or a swing in the direction of the ray, when the substance is said to be *right-handed*, or to the left, when it is called *left-handed*.

This phenomenon is theoretically possible with all crystals of a given system belonging to any of the classes of lower symmetry than the normal class which show a trigonal, hexagonal, or tetrahedral of the faces*, or, more simply, those in which the corresponding right-angle, left-angle, and typical forms are enantiomorphic (pp. 23, 84, 129) as noted in the chapter on crystallography. In crystallography this subject is more important with the common species of quartz, of the rhombohedral-trigonal class, and a further discussion of it is postponed to page 402, Art. 402.

367. Abnormal Interference Colors. Certain factors may at times modify the interference colors shown by a mineral section so as to produce abnormal effects. The most common cause is the natural color (or absorption) of the mineral section itself. If this is strong, the interference colors may be considerably changed. Certain minerals may show quite different tints (green for different wave-lengths of light). In some cases, a mineral may have practically zero absorption for a certain color, or an λ , therefore that particular color will be lacking in its interference colors. Further in some cases the vibration directions may be considerably divergent for light of varying wave-lengths. The section might therefore be the position of expectation for one color when other colors could come through. In these various ways, therefore, interference colors may be produced.

OPTICAL INSTRUMENTS AND METHODS

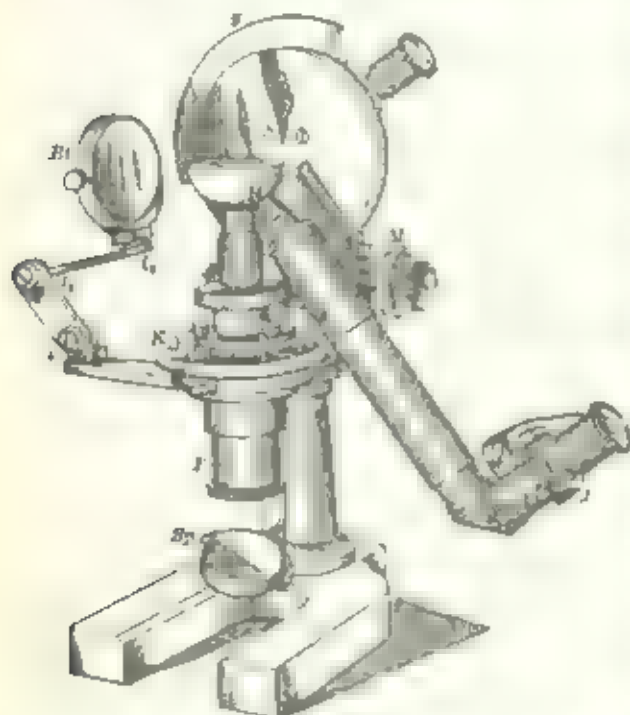
368. Measurement of Refractive Indices. Refractometer. For the determination of the refractive indices of crystals and of minerals various methods are employed. The most accurate results, when suitable material is at hand, may be obtained by a primary refractometer. This requires the observation of the angle of minimum deviation δ of a light-ray on passing through a prism of the given crystal having a known angle α , and with the edge cut in the proper direction. The accurate method of observation may be made with an ordinary refractometer or with the horizontal goniometer described in Art. 236. For the latter instrument the calcite crystal is so set that any being fastened to a ring of the tripod support, the beam of telescope with the vernier remains fixed. The other fork is used for the given crystal, the micrometer screw is turned so that the axis carrying the support and the vernier circle and observing telescope are horizontal. Light from a monochromatic source passes through an aperture slit and an image of this is thrown by the collimating optical prism. With a primary refracting substance two images are produced at the angle of minimum deviation must be measured

* Of the three low-symmetry classes among crystals the following seven may be characterized by an λ for α and β (based on $\alpha = 2$, $\beta = 1$): 1. $\alpha = 120^\circ$, $\beta = 120^\circ$, 17, p. 118. 10, p. 120. 2. $\alpha = 120^\circ$, $\beta = 135^\circ$, 27, p. 145. 29, p. 156. 32, p. 165.

for each the proper direction for the edge of the prism in this case is discussed later. When n_1 and n_2 are known the formula in Art. 333 is used.

369 Total Refractometer. The principle of total reflection (Art. 328) may also be made use of to determine the refractive index. No prism is required but only a small fragment having a single polished surface; this may have any direction with respect to the crystal, and in other cases must have a definite orientation as described later. A number of different instruments have been devised by means of which indices of refraction may be measured

572



Total Refractometer

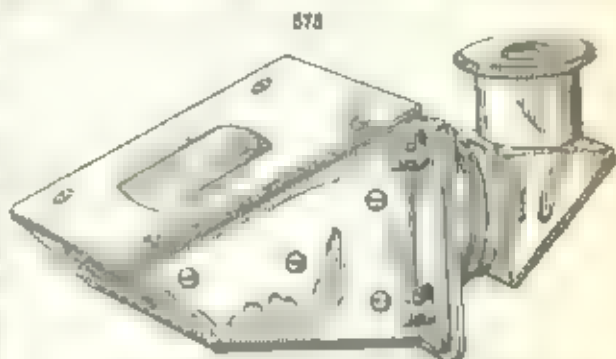
by the use of total reflection. A type which is used at present is represented in Fig. 572. This particular instrument was made by Loew. It consists of a hemisphere of glass (H) having a high refractive index which is mounted upon a glass post through which light may be reflected from the mirror M . The tube T contains a small prism so that when a thin section of a mineral is placed upon the plane surface of the hemisphere it is possible to obtain its optical orientation in the same manner as with the polarizing microscope. The polished mineral surface is placed upon the plane surface of H with a film of some light re-

fracting oil between them. Then a beam of light from some source of illumination, usually a monochromatic light, is reflected by means of the mirror M in such a way as to produce a small circular shadow upon the opposite side of the hemisphere. For further details of the operation see Art. 333. The telescope T is attached to the post (P) which in turn carries a scale on its edge. The telescope is moved up or down until the line between the light and dark portions of the field lies on the cross-hairs. The angle which is read on the scale under these conditions is the desired critical angle for the combination of the glass of the hemisphere and the mineral plate. Knowing this angle and the index of refraction of the glass of the hemisphere it is possible to calculate the index of refraction of the mineral. See Art. 333. Usually a table is furnished with the total refractometer by means of which the

desired refractive index is obtained directly from the value of the measured critical angle. The part carrying the glass hemisphere may be revolved in the horizontal plane and the angle of rotation measured on the scale *R*. This permits the measurement of indices corresponding to different vibration directions in the mineral. *L* is an eye lens which in combination with the other lenses of the tube *F* makes a low power microscope, which is used in the preliminary observations in order to center the mineral plate, etc. In the tube *A* is an iris diaphragm and usually a small Nicol prism that may be pushed in or out of the tube.

Fig. 573 represents a small total refractometer devised by G. F. H. Smith which depends upon the same principle. The mineral plate is placed upon the glass surface and when the top of the instrument is so held that light enters at the forward end and the totally reflected light is sent by means of a Nicol prism to the eyepiece. A scale is placed at the instrument in such a way that the boundary between the light and dark areas is seen superimposed upon it and so yields directly the value of the refractive index. For rapid and approximate determinations this instrument is very useful.

360 Tourmaline Tonge. A very simple form of polariscope for converging light is shown in Fig. 574. It is convenient in use, but of limited application. Here the polarizer and analyzer are two tourmaline plates such as



Small Total Refractometer. Actual Size



Tourmaline Tonge

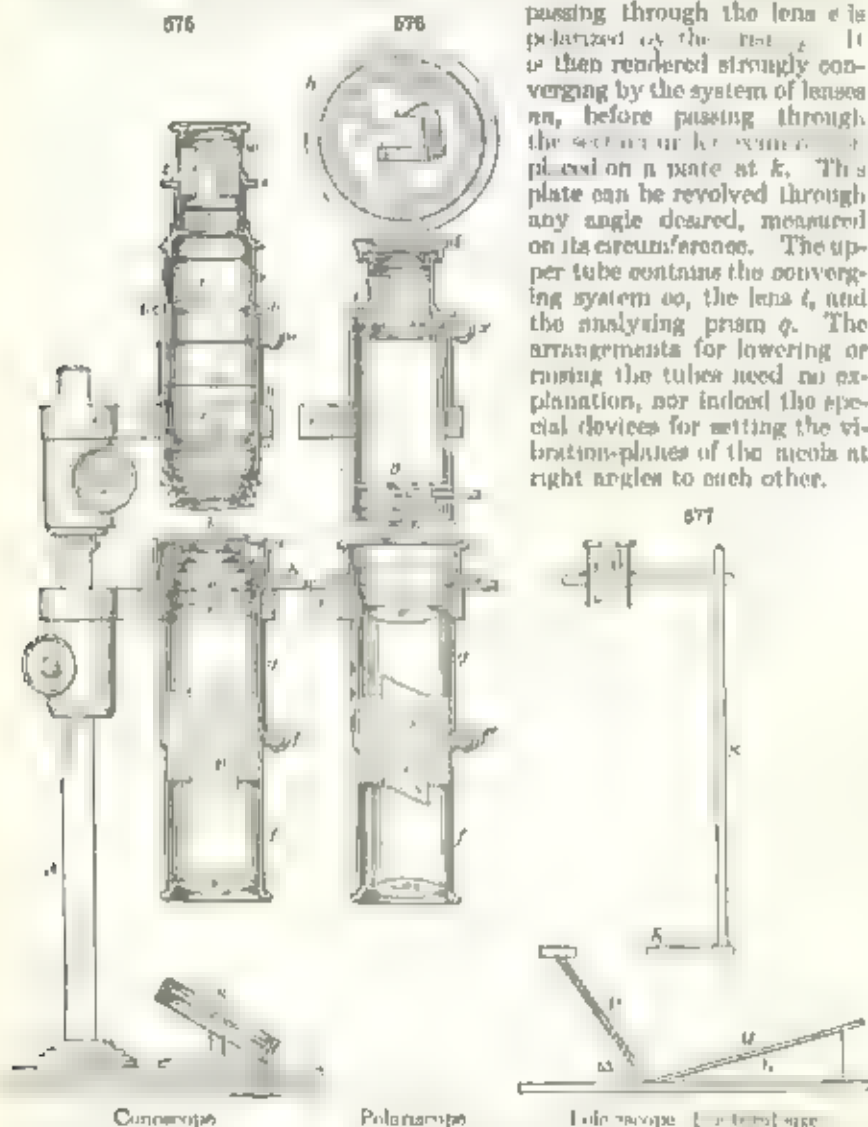
were described in Art. 348. They are mounted in pieces of cork and held in a kind of wire pincers. The object to be examined is placed between them and supported there by the spring in the wire. In use they are held close to the eye and in this position the crystal section is viewed in converging polarized light, with the result of showing (under proper conditions) the axial interference-figures. Arts. 397 and 417.

361 Polariscopes Conoscopes. — The common forms of polariscopes employing Nicol prisms are shown in Figs. 575 and 576. Fig. 575 represents

* These figures are taken from the catalogue of Fuoss.

the instrument arranged for converging light, which is often called a *conoscope*.

The essential parts are the mirror *S*, reflecting the light, which after passing through the lens *e* is polarized by the prism *p*. It is then rendered strongly converging by the system of lenses *aa*, before passing through the second or *hermann* prism placed on a plate at *k*. This plate can be revolved through any angle desired, measured on its circumference. The upper tube contains the converging system *aa*, the lens *e*, and the analysing prism *q*. The arrangements for lowering or raising the tubes need no explanation, nor indeed the special devices for setting the vibration-planes of the nicols at right angles to each other.

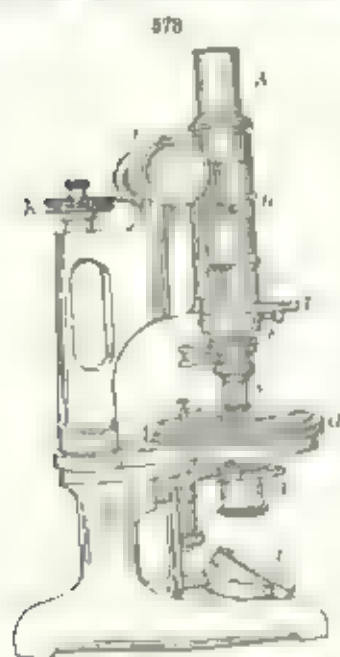


The accompanying tube (Fig. 576) shows the arrangement for observations in parallel light, the converging lenses having been removed.

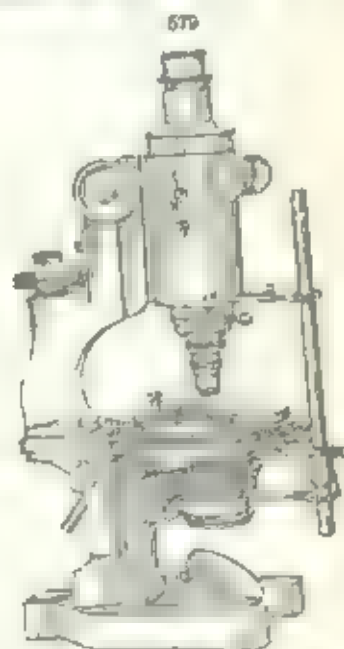
Fig. 577 represents in cross-section a simple, inexpensive but quite efficient form of polariscopes. The polarizing device, *P*, is in the form of two or three

thin glass sheets, the back of the bottom one being blackened. These glass plates are set at the appropriate angle to secure the maximum amount of polarization of the light reflected from them up through the opening in the stage. *M* represents an adjustable mirror by means of which light is reflected upon *P*. The analyzer, *A*, is instead of a plate which is held over the opening in the stage by means of a few strands of silk. A test series of lenses may be placed upon the stage of the instrument and so convert it into a microscope.

362. Polarization-Microscope—The investigation of the form and optical properties of minerals when cut in thin sections is best facilitated by the use of microscopes* specially adapted for this purpose. First are



Petrographic Microscope
Laboratory Model, Binocular
Type, 1 inch focal length



Petrographic Microscope
Laboratory Model, Binocular
Type, 1 inch focal length

designed with reference to the special study of minerals as seen in thin sections of rocks, they have now been so elaborated as largely to take the place of an older general instrument. They not only show of the characteristic of the optical properties of minerals with greater facility, but are applicable to many cases where the specimen had been too small for other means.

A highly serviceable microscope is the Laboratory Model made by the Bausch and Lomb Optical Co. and illustrated in Fig. 570. The essential arrangements of this instrument are as follows: The eyepiece at *d*, which is

* For detailed description of the petrographic microscope and its use see *Methods of Petrographic Research*, etc., *Manual of Petrographic Methods*, Wright. *The Methods of Petrographic Research*, etc.

removable, contains the cross-hairs with an eye lens adjustable for focusing upon target. At B is a Bertrand lens that screws in and out of the tube with an iris diaphragm attached to rotate it. At C is the analyzer box which screws in and out of the body tube. This prism may be revolved through a quarter turn. Lens D is in the eyepiece tube with a dust-proof shutter for the introduction of various accessories, such as the prism wedge, etc. At E is the microscope which can be centered, by the two screws which work at right angles to the A and L positions. The objective F is in a plate by a spring clamp and is quickly detached. The stage, G, revolves and carries a scale graduated in centimeters, the attached vernier permitting a reading of angles to thousandths of a centimeter. The stage micrometer carries a reading scale, iris diaphragm, and the polarizing prism. It can be moved upward and downward by means of a screw head and when a microscope is in use can be spring to the surface of the prism axis. The error in the angle scale and has a correction table for curve surface. The coarse focusing is by screw at J, where the microscope at K provides a fine adjustment by means of which a vertical movement of 0.0005 mm. can be read.

363. The Rosemount Model of the Biot and Tourmaline microscope is illustrated in Fig. 57a. This instrument is portable, after one described by Wright to whose works reference should be made for more details, according to the outstanding features of the instrument may be readily summarized as follows. It has a large body tube with which are dovetail connected the analyzer and the detector, each both with a very fine and a scale the optical axis of the microscope. The wave boards are characterized by means of a right hand and rotated about a central axis through an arc of 90°. The axes of the instrument of extension are 10 cm., to be made with the necessary revolving the stage and is a convenient, thereby allowing the instrument to be observed in exactly the same position as the method. The stage can be vertically adjusted and the same engraved with the stage so that the angle of rotation of the boards can be accurately measured. The polarizing prism can be entirely removed from the optical axis. A revolving mirror or sensitive plate is attached to the iris diaphragm in front of the stage.

When it be a decided instrument of different makes of petrographic microscope, the excellent size available. In the case of characters, however, they do not differ materially from those described above.

GENERAL OPTICAL CHARACTERS OF MINERALS

364. There are certain characteristics belonging to all minerals alike, crystalline and non-crystallized in their relation to light. These are:

1. DIAPHANEITY depending on the refractive index of light transmitted.
2. COLOR depending on the kind of light reflected or transmitted, as determined by the selective absorption.
3. LUSTER depending on the power and manner of reflecting light.

1. DIAPHANEITY

365. Degrees of Transparency — The amount of light transmitted by a substance varies in direct proportion, in other words, more or less light may be absorbed in the passage through the given substance (see Art. 336). The amount

of absorption is a minimum in a transparent solid, as ice, while it is greatest in one which is opaque, as iron. The following terms are adopted to express the different degrees in the power of transmitting light.

Transparent: when the outline of an object seen through the mineral is perfectly distinct.

Subtransparent or semi-transparent when objects are seen but the outlines are not distinct.

Translucent when light is transmitted but objects are not seen.

Diaphanous when nearly transparent, but objects are translucent. When light is transmitted even in the edge of a mineral the mineral is said to be *diaphanous*. It is a perfectly correct term since no substance fails to transmit some light, & most substances are translucent in some degree. It is perfectly true that some substances are so thin as to be translucent in which case it transmits a great deal of light.

The property of diaphanous minerals is that they are kept free from nearly perfect opacity by the presence of many materials present, in their numerous varieties nearly all the different degrees.

2. COLOR.

336 Nature of Color. As briefly explained in Art. 319, the sensation of color depends in the case of such chromatic light solely upon the length of the waves of light which meet the eye. If the presence of various wave-lengths is to be the combined effect of those that the sensation of color is due.

Further, since the light ordinarily employed is essentially white light, that is, a mixture of all the waves, light corresponding to the successive colors of the spectrum, the color of a body depends upon the selective absorption (see Art. 336) which it exerts upon the light transmitted, or reflected by it. A yellow mineral, for instance, absorbs all the waves of light excepting with the exception of those which give rise to the sensation of yellow. In general, the color which the eye perceives is the result of the mixture of those waves which are not absorbed.

337 Streak. The color of the powder of a mineral as obtained by scratching the surface of the mineral with a knife or file is the *streak* of the mineral, and is found by rubbing it on an unglazed porcelain surface, or called the *streak*. The *streak* is a very important property in distinguishing minerals. This is especially true with minerals having a metallic luster, as shown in Art. 370.

338 Dichroism, Pleochroism. - The selective absorption to which the color of a mineral is due, more especially by transmission, gives rise to colors with the crystallographic position to which the light is brought. It is hence one of the special optical characters referring upon the crystallization, which are discussed later. Here being a discussion of *dichroism*, the property of exhibiting different colors in different crystallographic directions by transmitted light. This subject is explained further in Arts. 401 and 423.

339, Varieties of Color. The following eight colors were selected by Werner as fundamental to facilitate the description of this character in the description of minerals: white, gray, black, blue, green, yellow, red and brown.

11 The varieties of Metals: Colors recognized are as follows:

1. *Copper* of course proper 2. *Bronze-green* pyrite 3. *Bronze-yellow* 4. *Yellowish* 5. *Gold* 6. *Silver* 7. *Iron* 8. *Steel* 9. *Lead* 10. *Aluminum* 11. *Platinum* 12. *Antimony* 13. *As* 14. *Sn* 15. *Pb* 16. *Fe* 17. *Al* 18. *Pt* 19. *Sb* 20. *As* 21. *Sn* 22. *Pb* 23. *Fe* 24. *Al* 25. *Pt* 26. *Sb* 27. *As* 28. *Sn* 29. *Pb* 30. *Fe* 31. *Al* 32. *Pt* 33. *Sb* 34. *As* 35. *Sn* 36. *Pb* 37. *Fe* 38. *Al* 39. *Pt* 40. *Sb* 41. *As* 42. *Sn* 43. *Pb* 44. *Fe* 45. *Al* 46. *Pt* 47. *Sb* 48. *As* 49. *Sn* 50. *Pb* 51. *Fe* 52. *Al* 53. *Pt* 54. *Sb* 55. *As* 56. *Sn* 57. *Pb* 58. *Fe* 59. *Al* 60. *Pt* 61. *Sb* 62. *As* 63. *Sn* 64. *Pb* 65. *Fe* 66. *Al* 67. *Pt* 68. *Sb* 69. *As* 70. *Sn* 71. *Pb* 72. *Fe* 73. *Al* 74. *Pt* 75. *Sb* 76. *As* 77. *Sn* 78. *Pb* 79. *Fe* 80. *Al* 81. *Pt* 82. *Sb* 83. *As* 84. *Sn* 85. *Pb* 86. *Fe* 87. *Al* 88. *Pt* 89. *Sb* 90. *As* 91. *Sn* 92. *Pb* 93. *Fe* 94. *Al* 95. *Pt* 96. *Sb* 97. *As* 98. *Sn* 99. *Pb* 100. *Fe* 101. *Al* 102. *Pt* 103. *Sb* 104. *As* 105. *Sn* 106. *Pb* 107. *Fe* 108. *Al* 109. *Pt* 110. *Sb* 111. *As* 112. *Sn* 113. *Pb* 114. *Fe* 115. *Al* 116. *Pt* 117. *Sb* 118. *As* 119. *Sn* 120. *Pb* 121. *Fe* 122. *Al* 123. *Pt* 124. *Sb* 125. *As* 126. *Sn* 127. *Pb* 128. *Fe* 129. *Al* 130. *Pt* 131. *Sb* 132. *As* 133. *Sn* 134. *Pb* 135. *Fe* 136. *Al* 137. *Pt* 138. *Sb* 139. *As* 140. *Sn* 141. *Pb* 142. *Fe* 143. *Al* 144. *Pt* 145. *Sb* 146. *As* 147. *Sn* 148. *Pb* 149. *Fe* 150. *Al* 151. *Pt* 152. *Sb* 153. *As* 154. *Sn* 155. *Pb* 156. *Fe* 157. *Al* 158. *Pt* 159. *Sb* 160. *As* 161. *Sn* 162. *Pb* 163. *Fe* 164. *Al* 165. *Pt* 166. *Sb* 167. *As* 168. *Sn* 169. *Pb* 170. *Fe* 171. *Al* 172. *Pt* 173. *Sb* 174. *As* 175. *Sn* 176. *Pb* 177. *Fe* 178. *Al* 179. *Pt* 180. *Sb* 181. *As* 182. *Sn* 183. *Pb* 184. *Fe* 185. *Al* 186. *Pt* 187. *Sb* 188. *As* 189. *Sn* 190. *Pb* 191. *Fe* 192. *Al* 193. *Pt* 194. *Sb* 195. *As* 196. *Sn* 197. *Pb* 198. *Fe* 199. *Al* 200. *Pt* 201. *Sb* 202. *As* 203. *Sn* 204. *Pb* 205. *Fe* 206. *Al* 207. *Pt* 208. *Sb* 209. *As* 210. *Sn* 211. *Pb* 212. *Fe* 213. *Al* 214. *Pt* 215. *Sb* 216. *As* 217. *Sn* 218. *Pb* 219. *Fe* 220. *Al* 221. *Pt* 222. *Sb* 223. *As* 224. *Sn* 225. *Pb* 226. *Fe* 227. *Al* 228. *Pt* 229. *Sb* 230. *As* 231. *Sn* 232. *Pb* 233. *Fe* 234. *Al* 235. *Pt* 236. *Sb* 237. *As* 238. *Sn* 239. *Pb* 240. *Fe* 241. *Al* 242. *Pt* 243. *Sb* 244. *As* 245. *Sn* 246. *Pb* 247. *Fe* 248. *Al* 249. *Pt* 250. *Sb* 251. *As* 252. *Sn* 253. *Pb* 254. *Fe* 255. *Al* 256. *Pt* 257. *Sb* 258. *As* 259. *Sn* 260. *Pb* 261. *Fe* 262. *Al* 263. *Pt* 264. *Sb* 265. *As* 266. *Sn* 267. *Pb* 268. *Fe* 269. *Al* 270. *Pt* 271. *Sb* 272. *As* 273. *Sn* 274. *Pb* 275. *Fe* 276. *Al* 277. *Pt* 278. *Sb* 279. *As* 280. *Sn* 281. *Pb* 282. *Fe* 283. *Al* 284. *Pt* 285. *Sb* 286. *As* 287. *Sn* 288. *Pb* 289. *Fe* 290. *Al* 291. *Pt* 292. *Sb* 293. *As* 294. *Sn* 295. *Pb* 296. *Fe* 297. *Al* 298. *Pt* 299. *Sb* 300. *As* 301. *Sn* 302. *Pb* 303. *Fe* 304. *Al* 305. *Pt* 306. *Sb* 307. *As* 308. *Sn* 309. *Pb* 310. *Fe* 311. *Al* 312. *Pt* 313. *Sb* 314. *As* 315. *Sn* 316. *Pb* 317. *Fe* 318. *Al* 319. *Pt* 320. *Sb* 321. *As* 322. *Sn* 323. *Pb* 324. *Fe* 325. *Al* 326. *Pt* 327. *Sb* 328. *As* 329. *Sn* 330. *Pb* 331. *Fe* 332. *Al* 333. *Pt* 334. *Sb* 335. *As* 336. *Sn* 337. *Pb* 338. *Fe* 339. *Al* 340. *Pt* 341. *Sb* 342. *As* 343. *Sn* 344. *Pb* 345. *Fe* 346. *Al* 347. *Pt* 348. *Sb* 349. *As* 350. *Sn* 351. *Pb* 352. *Fe* 353. *Al* 354. *Pt* 355. *Sb* 356. *As* 357. *Sn* 358. *Pb* 359. *Fe* 360. *Al* 361. *Pt* 362. *Sb* 363. *As* 364. *Sn* 365. *Pb* 366. *Fe* 367. *Al* 368. *Pt* 369. *Sb* 370. *As* 371. *Sn* 372. *Pb* 373. *Fe* 374. *Al* 375. *Pt* 376. *Sb* 377. *As* 378. *Sn* 379. *Pb* 380. *Fe* 381. *Al* 382. *Pt* 383. *Sb* 384. *As* 385. *Sn* 386. *Pb* 387. *Fe* 388. *Al* 389. *Pt* 390. *Sb* 391. *As* 392. *Sn* 393. *Pb* 394. *Fe* 395. *Al* 396. *Pt* 397. *Sb* 398. *As* 399. *Sn* 400. *Pb* 401. *Fe* 402. *Al* 403. *Pt* 404. *Sb* 405. *As* 406. *Sn* 407. *Pb* 408. *Fe* 409. *Al* 410. *Pt* 411. *Sb* 412. *As* 413. *Sn* 414. *Pb* 415. *Fe* 416. *Al* 417. *Pt* 418. *Sb* 419. *As* 420. *Sn* 421. *Pb* 422. *Fe* 423. *Al* 424. *Pt* 425. *Sb* 426. *As* 427. *Sn* 428. *Pb* 429. *Fe* 430. *Al* 431. *Pt* 432. *Sb* 433. *As* 434. *Sn* 435. *Pb* 436. *Fe* 437. *Al* 438. *Pt* 439. *Sb* 440. *As* 441. *Sn* 442. *Pb* 443. *Fe* 444. *Al* 445. *Pt* 446. *Sb* 447. *As* 448. *Sn* 449. *Pb* 450. *Fe* 451. *Al* 452. *Pt* 453. *Sb* 454. *As* 455. *Sn* 456. *Pb* 457. *Fe* 458. *Al* 459. *Pt* 460. *Sb* 461. *As* 462. *Sn* 463. *Pb* 464. *Fe* 465. *Al* 466. *Pt* 467. *Sb* 468. *As* 469. *Sn* 470. *Pb* 471. *Fe* 472. *Al* 473. *Pt* 474. *Sb* 475. *As* 476. *Sn* 477. *Pb* 478. *Fe* 479. *Al* 480. *Pt* 481. *Sb* 482. *As* 483. *Sn* 484. *Pb* 485. *Fe* 486. *Al* 487. *Pt* 488. *Sb* 489. *As* 490. *Sn* 491. *Pb* 492. *Fe* 493. *Al* 494. *Pt* 495. *Sb* 496. *As* 497. *Sn* 498. *Pb* 499. *Fe* 500. *Al* 501. *Pt* 502. *Sb* 503. *As* 504. *Sn* 505. *Pb* 506. *Fe* 507. *Al* 508. *Pt* 509. *Sb* 510. *As* 511. *Sn* 512. *Pb* 513. *Fe* 514. *Al* 515. *Pt* 516. *Sb* 517. *As* 518. *Sn* 519. *Pb* 520. *Fe* 521. *Al* 522. *Pt* 523. *Sb* 524. *As* 525. *Sn* 526. *Pb* 527. *Fe* 528. *Al* 529. *Pt* 530. *Sb* 531. *As* 532. *Sn* 533. *Pb* 534. *Fe* 535. *Al* 536. *Pt* 537. *Sb* 538. *As* 539. *Sn* 540. *Pb* 541. *Fe* 542. *Al* 543. *Pt* 544. *Sb* 545. *As* 546. *Sn* 547. *Pb* 548. *Fe* 549. *Al* 550. *Pt* 551. *Sb* 552. *As* 553. *Sn* 554. *Pb* 555. *Fe* 556. *Al* 557. *Pt* 558. *Sb* 559. *As* 560. *Sn* 561. *Pb* 562. *Fe* 563. *Al* 564. *Pt* 565. *Sb* 566. *As* 567. *Sn* 568. *Pb* 569. *Fe* 570. *Al* 571. *Pt* 572. *Sb* 573. *As* 574. *Sn* 575. *Pb* 576. *Fe* 577. *Al* 578. *Pt* 579. *Sb* 580. *As* 581. *Sn* 582. *Pb* 583. *Fe* 584. *Al* 585. *Pt* 586. *Sb* 587. *As* 588. *Sn* 589. *Pb* 590. *Fe* 591. *Al* 592. *Pt* 593. *Sb* 594. *As* 595. *Sn* 596. *Pb* 597. *Fe* 598. *Al* 599. *Pt* 600. *Sb* 601. *As* 602. *Sn* 603. *Pb* 604. *Fe* 605. *Al* 606. *Pt* 607. *Sb* 608. *As* 609. *Sn* 610. *Pb* 611. *Fe* 612. *Al* 613. *Pt* 614. *Sb* 615. *As* 616. *Sn* 617. *Pb* 618. *Fe* 619. *Al* 620. *Pt* 621. *Sb* 622. *As* 623. *Sn* 624. *Pb* 625. *Fe* 626. *Al* 627. *Pt* 628. *Sb* 629. *As* 630. *Sn* 631. *Pb* 632. *Fe* 633. *Al* 634. *Pt* 635. *Sb* 636. *As* 637. *Sn* 638. *Pb* 639. *Fe* 640. *Al* 641. *Pt* 642. *Sb* 643. *As* 644. *Sn* 645. *Pb* 646. *Fe* 647. *Al* 648. *Pt* 649. *Sb* 650. *As* 651. *Sn* 652. *Pb* 653. *Fe* 654. *Al* 655. *Pt* 656. *Sb* 657. *As* 658. *Sn* 659. *Pb* 660. *Fe* 661. *Al* 662. *Pt* 663. *Sb* 664. *As* 665. *Sn* 666. *Pb* 667. *Fe* 668. *Al* 669. *Pt* 670. *Sb* 671. *As* 672. *Sn* 673. *Pb* 674. *Fe* 675. *Al* 676. *Pt* 677. *Sb* 678. *As* 679. *Sn* 680. *Pb* 681. *Fe* 682. *Al* 683. *Pt* 684. *Sb* 685. *As* 686. *Sn* 687. *Pb* 688. *Fe* 689. *Al* 690. *Pt* 691. *Sb* 692. *As* 693. *Sn* 694. *Pb* 695. *Fe* 696. *Al* 697. *Pt* 698. *Sb* 699. *As* 700. *Sn* 701. *Pb* 702. *Fe* 703. *Al* 704. *Pt* 705. *Sb* 706. *As* 707. *Sn* 708. *Pb* 709. *Fe* 710. *Al* 711. *Pt* 712. *Sb* 713. *As* 714. *Sn* 715. *Pb* 716. *Fe* 717. *Al* 718. *Pt* 719. *Sb* 720. *As* 721. *Sn* 722. *Pb* 723. *Fe* 724. *Al* 725. *Pt* 726. *Sb* 727. *As* 728. *Sn* 729. *Pb* 730. *Fe* 731. *Al* 732. *Pt* 733. *Sb* 734. *As* 735. *Sn* 736. *Pb* 737. *Fe* 738. *Al* 739. *Pt* 740. *Sb* 741. *As* 742. *Sn* 743. *Pb* 744. *Fe* 745. *Al* 746. *Pt* 747. *Sb* 748. *As* 749. *Sn* 750. *Pb* 751. *Fe* 752. *Al* 753. *Pt* 754. *Sb* 755. *As* 756. *Sn* 757. *Pb* 758. *Fe* 759. *Al* 760. *Pt* 761. *Sb* 762. *As* 763. *Sn* 764. *Pb* 765. *Fe* 766. *Al* 767. *Pt* 768. *Sb* 769. *As* 770. *Sn* 771. *Pb* 772. *Fe* 773. *Al* 774. *Pt* 775. *Sb* 776. *As* 777. *Sn* 778. *Pb* 779. *Fe* 780. *Al* 781. *Pt* 782. *Sb* 783. *As* 784. *Sn* 785. *Pb* 786. *Fe* 787. *Al* 788. *Pt* 789. *Sb* 790. *As* 791. *Sn* 792. *Pb* 793. *Fe* 794. *Al* 795. *Pt* 796. *Sb* 797. *As* 798. *Sn* 799. *Pb* 800. *Fe* 801. *Al* 802. *Pt* 803. *Sb* 804. *As* 805. *Sn* 806. *Pb* 807. *Fe* 808. *Al* 809. *Pt* 810. *Sb* 811. *As* 812. *Sn* 813. *Pb* 814. *Fe* 815. *Al* 816. *Pt* 817. *Sb* 818. *As* 819. *Sn* 820. *Pb* 821. *Fe* 822. *Al* 823. *Pt* 824. *Sb* 825. *As* 826. *Sn* 827. *Pb* 828. *Fe* 829. *Al* 830. *Pt* 831. *Sb* 832. *As* 833. *Sn* 834. *Pb* 835. *Fe* 836. *Al* 837. *Pt* 838. *Sb* 839. *As* 840. *Sn* 841. *Pb* 842. *Fe* 843. *Al* 844. *Pt* 845. *Sb* 846. *As* 847. *Sn* 848. *Pb* 849. *Fe* 850. *Al* 851. *Pt* 852. *Sb* 853. *As* 854. *Sn* 855. *Pb* 856. *Fe* 857. *Al* 858. *Pt* 859. *Sb* 860. *As* 861. *Sn* 862. *Pb* 863. *Fe* 864. *Al* 865. *Pt* 866. *Sb* 867. *As* 868. *Sn* 869. *Pb* 870. *Fe* 871. *Al* 872. *Pt* 873. *Sb* 874. *As* 875. *Sn* 876. *Pb* 877. *Fe* 878. *Al* 879. *Pt* 880. *Sb* 881. *As* 882. *Sn* 883. *Pb* 884. *Fe* 885. *Al* 886. *Pt* 887. *Sb* 888. *As* 889. *Sn* 890. *Pb* 891. *Fe* 892. *Al* 893. *Pt* 894. *Sb* 895. *As* 896. *Sn* 897. *Pb* 898. *Fe* 899. *Al* 900. *Pt* 901. *Sb* 902. *As* 903. *Sn* 904. *Pb* 905. *Fe* 906. *Al* 907. *Pt* 908. *Sb* 909. *As* 910. *Sn* 911. *Pb* 912. *Fe* 913. *Al* 914. *Pt* 915. *Sb* 916. *As* 917. *Sn* 918. *Pb* 919. *Fe* 920. *Al* 921. *Pt* 922. *Sb* 923. *As* 924. *Sn* 925. *Pb* 926. *Fe* 927. *Al* 928. *Pt* 929. *Sb* 930. *As* 931. *Sn* 932. *Pb* 933. *Fe* 934. *Al* 935. *Pt* 936. *Sb* 937. *As* 938. *Sn* 939. *Pb* 940. *Fe* 941. *Al* 942. *Pt* 943. *Sb* 944. *As* 945. *Sn* 946. *Pb* 947. *Fe* 948. *Al* 949. *Pt* 950. *Sb* 951. *As* 952. *Sn* 953. *Pb* 954. *Fe* 955. *Al* 956. *Pt* 957. *Sb* 958. *As* 959. *Sn* 960. *Pb* 961. *Fe* 962. *Al* 963. *Pt* 964. *Sb* 965. *As* 966. *Sn* 967. *Pb* 968. *Fe* 969. *Al* 970. *Pt* 971. *Sb* 972. *As* 973. *Sn* 974. *Pb* 975. *Fe* 976. *Al* 977. *Pt* 978. *Sb* 979. *As* 980. *Sn* 981. *Pb* 982. *Fe* 983. *Al* 984. *Pt* 985. *Sb* 986. *As* 987. *Sn* 988. *Pb* 989. *Fe* 990. *Al* 991. *Pt* 992. *Sb* 993. *As* 994. *Sn* 995. *Pb* 996. *Fe* 997. *Al* 998. *Pt* 999. *Sb* 1000. *As*

12 The varieties of Non-metallic Colors

1. *White* 2. *Yellowish* 3. *Orange* 4. *Red* 5. *Orange-red* 6. *Reddish* 7. *Reddish-brown* 8. *Brown* 9. *Black* 10. *Gray* 11. *Greenish* 12. *Blue* 13. *Blue-gray* 14. *Gray-blue* 15. *Gray* 16. *Yellowish-gray* 17. *Gray* 18. *Blackish* 19. *Black* 20. *Gray* 21. *Blackish-gray* 22. *Black* 23.

3. LUSTER

370. Nature of Luster. — The luster of minerals varies with the nature of their surfaces. A variation in the quantity of light reflected produces different degrees of intensity of luster, a variation in the nature of the reflecting surface produces different kinds of luster.

371. Kinds of Luster. — The kinds of luster recognized are as follows:

1 **METALLIC** the luster of the metals as of gold, copper, iron, &c.

In general, a mineral is not said to have metallic luster unless it is opaque in the mass, opaque surface lusters do transmit so light that the edges of thin splinters. Some minerals have varieties with metallic and others with non-metallic luster, this is true of arsenic.

Imperfect metallic luster is expressed by the term *sub-metallic*, as illustrated by columbite, wolframate. Other kinds of luster are described briefly as **NON-METALLIC**.

2 **NON-METALLIC** 4 **Adamantine** the luster of the diamond. When also sub-metallic it is termed *metallic adamantine*, as cerussite, pyrrhotite.

A luster is termed *adamantine* in substances of high refractive index. It is usually connected with their relatively great density and hardness, as with the diamond, also corundum, etc., or because they contain heavy molecules, thus most compounds of lead and metals in luster have a high refractive index and an adamantine luster.

5 **Vitreous** the luster of broken glass. An perfectly vitreous luster is termed *subvitreous*. The vitreous or sub-vitreous lusters are the most common in the mineral kingdom. Quartz possesses the former in an eminent degree; calcite, often the latter.

6 **Resinous** luster of the yellow resins as opal, and some yellow varieties of apatite.

7 **Greasy** luster of oily glass. This is near resinous luster, but is of a quite as not as asphalt.

8 **Pearly** like pearl, as the brucite, stibite, etc. When united with sub-metallic or sub-vitreous the term *metallic pearly* is used.

Pearly luster belongs to the glassy luster in a piece of thin glass-plates, especially it is exhibited by minerals, which having a perfect cleavage, may be partially separated into successive plates, as the black *graphite* of a crystalline. It is also shown for a like reason, by foliated minerals, as *slate* and *micaceous*.

9 **Silky** like silk, it is the result of a fibrous structure, as fibrous calcite, fibrous gypsum.

The different degrees and kinds of luster are best exhibited differently by unlike faces of the same crystal, but always similarly by like faces. For example the basal plane of apophyllite has a pearly luster whereas the prismatic faces, which have a vitreous luster.

As shown by Haidinger, only vitreous, adamantine and metallic lusters belong to perfect uniaxial crystals. In the first, the refractive index of the crystal is $\frac{1}{2} \sqrt{2}$, in the second, $\frac{1}{2} \sqrt{2}$, in the third, about 2.5. The true difference between metallic and vitreous metal is due to the effect which the different surfaces, upon the reflected light, in general, the luster is produced on the faces of well-developed crystalline forms, particularly if the light reflected from a metallic surface is also partly a mirror or by the microscope of Haidinger Art 401, it will be found that for a ray, that vibrates in the plane of incidence and that whose vibrations are motion as a, its color and nature the color of the material and vibrating in the plane of incidence of the light reflected by a vitreous substance, these rays whose vibrations are at right angles to the plane of incidence are more or less polarized, and are colorless, while those whose vibrations

are in this plane having penetrated somewhat into the rock, and a flared, some absorption, show the color of the mineral inside. A piece of rock glass thus examined, will show a crystalline and a real luster. Adamantine luster occupies a position between the others.

372. Degrees of Luster. The degrees of intensity of luster are classified as follows:

1. *Specular* reflecting with brilliancy and giving well-defined images, as hematite, cassiterite.

2. *Splendous* producing an image by reflection, but not one well-defined, as celestine.

3. *Glistening* affording a general reflection from the surface, but no image, as talc, chloropyrite.

4. *Glittering* affording imperfect reflection and apparently from points over the surface, as talc, obsidian, etc.

A mineral is said to be dull when there is a total absence of luster, as chalk, the others, and so on.

373. Play of Colors. Opalescence. Iridescence. The term *play of colors* is used to describe the appearance of several prismatic colors in rapid succession on turning the mineral. This property belongs in perfection to the diamond, in which it is due to its high dispersive power. It is also observed in precious opal, where it is explained on the principle of interference, in this case it is most brilliant by cat's-paw light.

The expression *change of colors* is used when each particular color appears to pervade a larger space than in the play of colors and to succeed it produced by turning the mineral in less rapid. This is shown in malachite as explained under that species.

Opalescence is a milky or pearly reflection from the interior of a specimen observed in transmitted and in cat's-paw.

Iridescence means an exhibition of prismatic colors in the interior or on the surface of a mineral. The phenomenon of a play of colors, as above, etc., are sometimes to be explained by the presence of minute foreign crystals, in particular positions. More generally, however, they are caused by a presence of fine laminae parallel to the light reflected from which a reflection takes place analogous to the well-known Newton's rings (see Art. 343).

374. Tarnish. A minable surface is tarnished when its color differs from that obtained by fracture, as is the case with specimens of corundum. A surface possesses the steel tarnish when it presents the superficial blue color of tempered steel, as columbite. The tarnish is most when it exhibits fixed prismatic colors, as is common with the hematite of China. These tarnish and the colors of minerals are owing to a thin surface film proceeding from different sources, either from a change in the surface of the mineral or from foreign crystallization, hydrated iron oxide is one of the most common sources of it and produces the colors of anthracite and hematite.

375. Asterism. This name is given to the peculiar star-like rays of light observed in certain directions in some minerals. This is seen by reflected light in the form of a six-rayed star in sapphires and is also well shown by transmitted light (use of a slit in flame) with the phlogopite mica from South Burgess, Canada. In the former case it is explained by the presence of thin twinning-lamellae symmetrically arranged. In the other case it is due to the presence of minute fibrous crystals also symmetrically arranged which are probably rutile or tourmaline in most cases. Crystalline faces which have been artificially etched also sometimes exhibit asterism. The peculiar light-

figures sometimes observed in reflected light on the faces of crystals, either natural or etched, are of similar nature.

376. Schillerization. — The general term *schiller* is applied to the peculiar luster, sometimes nearly metallic observed in certain directions in certain minerals, as conspicuously in schiller-spar, an altered variety of bromides, also in diatomee, hypersthene, smaltine and others. It is explained by a reflection either from minute inclined plates in parallel position or from the surfaces of minute cavities (negative crystals) having a common orientation. In many cases it is due to water which has developed these cavities or the cavities in the direction of solution-spar (see Art. 290). The process by which it has been produced is then called *schillerization*.

377. Fluorescence. — The emission of light from within a substance while it is being exposed to direct radiation or in certain cases to an electrical discharge in a vacuum tube, is called *fluorescence*. It is best exhibited by fluorite, from which the phenomenon got its name. Thus if a beam of white light be passed through a cone of colorless fluorite, a delicate violet color is radiated out in a path. This effect is entirely due to the action of the transmitted rays, and is connected with a change of refrangibility in the transmitted light.

The electrical discharge from the negative pole of a vacuum tube calls out a brilliant fluorescence not only with the diamond, the ruby and many gems, but also with residues of their minerals. Such substances may continue to emit light or phosphoresce after the discharge ceases.

378. Phosphorescence. — The continued emission of light by a substance (not necessarily produced especially after heating) exposure to light or to an electrical discharge, is called *phosphorescence*.

Fluorite becomes highly phosphorescent after being heated to about 150°C . Different varieties give off light of different colors, the *diophrase* variety, an optical gem, light blue or purple blue and reddish grey. This phosphorescence may be observed more darkly or by subjecting the pulverized mineral to a heat below redness. It may even be produced by a sharp blow with a hammer. Some varieties of white phosphoric or marble, if or might heating emit a yellow light, so also from ice, diamonds, and other species.

The X-ray and ultra violet light will produce phosphorescence in albino, kintzite, and some diamonds. The fact that white ice glows when exposed to ultraviolet light is made use of in testing the results from a white light screen make certain the separation has been complete. It has been estimated as cause certain minerals to phosphoresce in white light and white light.

Exposure to the light of the sun produces very apparent phosphorescence with many diamonds and some species are seen to be less than if they were. This property is not striking after exposure to the blue rays of the spectrum, when the red rays it is rapidly lost. A mixture of calcium sulphate and barium will phosphoresce for a considerable period after being exposed to sunlight.

379. Triboluminescence and Crystaloluminescence. — Certain crystallized substances become luminous when rubbed or scraped off. This property, known as *triboluminescence* is exhibited by some mineral crystals. Some varieties of splinter gave off light when scraped. Light is sometimes given off by certain substances in crystallizing from a solution. Arsenic oxide, As_2O_3 , is an example. This property is called *crystaloluminescence*.

SPECIAL OPTICAL CHARACTERS BELONGING TO CRYSTALS OF THE DIFFERENT SYSTEMS

380. All crystallized minerals may be grouped into three grand classes, which are distinguished by their physical properties, as well as their geometrical form. These three classes are as follows:

A. *Isometric*, embracing crystals of the isometric system, which are referred to three equal rectangular axes.

B. *Tetragonal and hexagonal*, embracing crystals of the tetragonal and hexagonal systems referred to two, or three, equal horizontal axes, and a third, or fourth, axis, perpendicular at right angles to their plane. Crystals of this class have a fixed, principal axis of crystallographic symmetry.

C. *Anorthic*, embracing the crystals of the orthorhombic, monoclinic, and triclinic systems referred to three unequal axes.

381. Isotropic Crystals. Of the three classes, the isometric class included crystals which, with respect to light and related phenomena involving heat, are not different from the Greek, *isotropa*, signifying *equal turning*. These are those which, by the action of proper external forces, may be distinguished by characteristics in the light rays (though they travel with equal velocity in all directions), provided that the material itself is not disturbed by external pressure or internal strain. If it be imagined, *suppose*, that light starts from a point within an isotropic medium at a given moment of time, the resulting wave surface will be a sphere.

It must be emphasized, however, that such a crystal is not isotropic with respect to those properties which depend directly upon the molecular structure, like solubility and elasticity. (See Art. 280.)

For example, *quartz*, such as glass and *calc*, which are destitute of any order in the crystalline structure, are those in which all directions are sensibly the same, and are isotropic, and not only with reference to light, but also as regards their capacity of heat and properties.

382. Anisotropic Crystals, Uniaxial and Biaxial. Crystals of the isometric and enantiometric classes, on the other hand, in their structure are different from the Greek, signifying *unequal turning*. Their optical properties are, in general, unlike in different directions, or more particularly, the velocity with which light is propagated varies with the direction of vibration.

Further, in crystals of the isometric class, that variable property of the light, other than which the velocity of propagation depends, remains constant for all directions with a certain *be*, or *figure*, for all those crystals inclined to the crystallographic axis. In the formation of this axis there is a double refraction, it is hence called the *optical axis*, and, the crystals of this class are said to be *uniaxial*.

Crystals of the other anisometric class have more complex optical relations requiring special explanation, but in general it may be stated that in them there are *two* axes, an *horizontal* and *vertical* is characteristic to the range of the axis spoken of above; hence, these crystals are said to be optically *biaxial*.

A. ISOMETRIC CRYSTALS

383. It has been stated that crystals of the isometric system are optically *isotropic*, and hence light travels with the same velocity in every direction in them. Light rays, therefore, suffer only single refraction in passing into and

isotropic medium, or, in other words, there can be but one value of the refractive index n for a given wave-length. If this be represented by n , while V is the velocity of light in air and v that in the given medium, then

$$n = \frac{V}{v}, \text{ or } v = \frac{V}{n}.$$

The wave-front for light-waves propagated from any point within such an isotropic medium is, as already stated, a sphere. The sphere, therefore, may be taken to represent the optical properties of an isotropic medium. Sections of a sphere normal to any diameter will always be circles. These circular sections with like radii in all directions correspond to the fact that the optical character of an isotropic substance is the same in all directions normal to the line of light propagation. Or in other words, light vibrations may take place in any direction normal to the direction of transmission, i. e., the light is not polarized. Further its velocity remains uniform no matter what may be the direction of its vibration.

This statement holds true of all the classes of isometric crystals. In other words, a crystal of maximum symmetry, as calcite and one having the restricted symmetry characteristic of the tetrahedral or pyritohedral systems, have alike the same isotropic character. Two of the classes, however, namely the trigonal and the tetartohedral classes, differ in this particular, that crystals belonging to them may exhibit what has already been defined (Art. 356) as circular polarization.

384. Behavior of Sections of Isometric Crystals in Polarized Light.

In consequence of their isotropic character, isometric crystals exhibit no special phenomena in polarized light. Any section of an isotropic substance (isometric crystal or some mineral or mineral) has no polarizing or doubly refracting effect upon light it does not change it. If the character of light that enters it from the polarizer of a polariscope. Therefore thin sections of isometric crystals when examined in a polariscope or polarizing microscope with the nicols crossed will appear dark in all positions. In other words, they are always extinguished. Further, when a crystal mineral is examined, without the analyzer there will be no change in its color when the section is revolved with the stage of the microscope. Some minerals are mentioned on a later page (Art. 441).

The single refractive index of an isotropic substance may be determined by means of a prism (see Art. 333) with its edge cut in any direction whatever.

B. UNIAXIAL CRYSTALS

General Optical Relations

385. The crystallographic and optical relations of crystals belonging to the tetragonal and hexagonal systems have already been briefly summarized (Art. 382), it now remains to develop their special characters more fully. This can be done most simply by making frequent use of the familiar conception of a light-ray to represent the character and motion of the light wave.

386. Behavior of Light in Uniaxial Minerals. — Light entering a uniaxial mineral is in general broken up into two rays which are perpendicular to each other and which travel with different velocities and therefore have different indices of refraction. One of the two rays derived from a single incident ray always vibrates in the plane of the horizontal crystal

tallographic axes. The other ray vibrates at right angles to the first and always in a vertical plane that includes the vertical crystallographic axis. The optical character of a uniaxial mineral is uniform for all directions lying in the horizontal crystallographic plane and therefore the ray whose vibration lies in this plane will have a constant velocity no matter what its direction of vibration is. This ray will therefore have a single and constant index of refraction commonly designated by ω . Since this ray follows the usual law as to the constant ratio between the sines of the angles of incidence and refraction and in general behaves in an ordinary way it is called the *ordinary ray*. The ray which vibrates in a plane that includes the vertical crystallographic axis will have the direction of vibration constantly changing as the direction of its path through the crystal changes and its velocity will correspondingly vary. Its index of refraction will therefore depend upon the direction of its propagation and it will not in general obey the usual sine law. This ray is therefore called an *extraordinary ray*.

When light travels in a uniaxial mineral in a direction parallel to the vertical crystallographic axis, essentially no vibrations need take place in the horizontal plane. It behaves wholly as the ordinary ray with a single velocity and refractive index. There can be no double refraction of light traveling along this direction and in this case the mineral will behave like an isotropic substance. This direction of no double refraction coincident with the vertical crystal axis is known as the *optical axis* and is the only one such direction in the crystallographic system called *uniaxial*. As soon as the direction of transmission becomes inclined to the vertical crystal axis the light is doubly refracted and as the inclination increases the direction of vibration of the light of the extraordinary ray departs more and more from the plane of vibration of the ordinary ray with a corresponding change in its velocity and refractive index. The difference between the refractive indices of the two rays becomes a maximum when the light passes through the mineral in a horizontal direction with the direction of vibration of the extraordinary ray parallel to the vertical crystal axis. (In other words as divergent as possible from the horizontal plane.) The value of the refractive index of the extraordinary ray when at its maximum difference from the constant index of the ordinary ray is the one always quoted and is indicated by ϵ . These two indices, ω and ϵ are called the *principal indices* of a uniaxial crystal. A *principal section* of a uniaxial crystal is a section passing through the vertical axis.

387 Positive and Negative Crystals. — Uniaxial crystals are divided into two classes depending upon whether the velocity of the extraordinary ray is greater or less than that of the ordinary ray. Those in which the refractive index of the ordinary ray, ω , is less than that of the extraordinary ray ϵ ($\omega < \epsilon$) are called *positive*. This is illustrated by quartz (for yellow sodium light).

$$\omega = 1.544. \quad \epsilon = 1.553$$

On the other hand, if ϵ is less than ω ($\epsilon < \omega$) the crystal is said to be *negative*.* Calcite is an example for which (for sodium light),

$$\omega = 1.658. \quad \epsilon = 1.486$$

Other examples are given later. Art. 391

* It will assist in remembering these remarks to note that the first vowel in the words positive and negative agrees with the symbol used for the smaller index of refraction in each case.

388. Determination of the Refractive Indices in Uniaxial Crystals.

The indices of refraction of uniaxial crystals are measured in exactly the same way as in the case of isotropic substances. With uniaxial crystals, however, the prism or plate used must be cut so that its optical axis is in one of its faces. If a prism is employed, its edge should be perpendicular to the optical axis or in other words parallel to the vertical crystal axis (Fig. 388). When, such a prism is examined by the refractometer, two refractive indices are seen, the angles of refraction of which can be measured by either the goniometer or the minimum deviation or prisms method, according to what is used in Art. 333. The two rays are polarized, the ordinary ray vibrating in the horizontal plane and the extraordinary ray vibrating in the vertical plane, the former at the edge of the prism. The plane of vibration of the extraordinary ray must be determined by the use of a Nicol prism held against the edge of the refractometer. When the plane of the prism is horizontal the extraordinary ray will be ordinary ray which is visible and when the plane of the prism is vertical only that of the extraordinary ray will appear. In this way the values of the two rays are determined and are positive or negative characters of the crystal are ascertained. It is possible to obtain these values from a comparison with 100 optically anisotropic minerals on which the same method is being tried that preparations are so great that such preparations are seldom used.

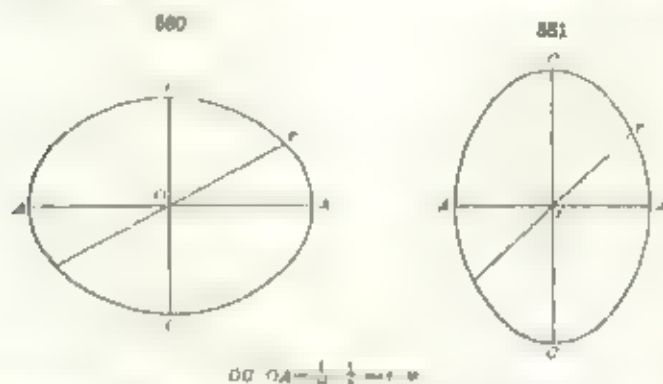
The method of total reflection is used a single plate will suffice provided it either has in the prism zone of the crystal or is parallel to the main plane. In each case two shadows will be observed corresponding to their position to the angles of total reflection of the two rays. When the plate is cut parallel to a face of the prism zone, the (these shadows, that is, belonging to the ordinary ray, will remain stationary as the plate is revolved on the hemisphere of the crystal refractometer while the shadow of the extraordinary ray will vary from being coincident with that of the ordinary ray to a certain maximum divergence from that position. This maximum interference position, which may stand a greater or less angle than that of the ordinary ray, depending upon the physical character of the mineral is the angle corresponding to the true value of the refractive index of the extraordinary ray. There will be two positions at 180° apart during the complete revolution of the specimen at which this value may be measured. If the plate was cut parallel to the basal plane of the crystal the two shadows would both be stationary during such a revolution and the value of the angle for both rays can be measured in any position of the plate.

In case the method of immersion in liquids of known refractive indices is used, it is important if possible to obtain the true values for ω and ϵ . In general, each mineral grain will yield two indices corresponding to the two vibration directions indicated by the positions of extinction of the grain. One of these places will belong to the ordinary ray and will definitely the value of ω . The other index which belongs to the extraordinary ray will vary with the crystal orientation of the grain. If a series of variously crystallized sections, the index having the maximum difference from ω will at least approximate to ϵ . If the grains are of uniform thickness, those that show the highest order of interference colors will give the closest approach to the true ϵ . On the other hand grains that show but only a little birefringence will give only the value for ω . If interference figures see Art. 397 can be obtained from the grains they will help in their identification and assist in finding the vibration direction of the extraordinary ray that will give the index ϵ .

389. Wave-surface. — Remembering that the velocity of light-propagation is always inversely proportional to the corresponding refractive index, it is obvious that the velocity of the ordinary ray for all directions in a uniaxial crystal must be the same, being uniformly proportional to $\frac{1}{\omega}$. In other words, supposing light originates at a point within a uniaxial crystal the ordinary ray would travel out in all directions with uniform velocity and its wave-front would form a sphere.

For the extraordinary ray, however, the velocity varies with the direction, being proportional to $\frac{1}{\omega}$ in a horizontal direction and becoming sensibly equal to $\frac{1}{\omega}$ when nearly coincident with the direction of the vertical axis. The

law of the varying change of velocity between these values, $\frac{1}{\omega}$ and $\frac{1}{\omega'}$, is given by an ellipse whose axes (OC , OA , Figs. 582, 584) are respectively proportional to the above values.

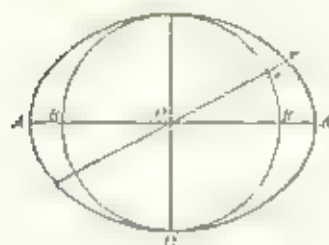


The wave-front of the extraordinary ray is then a spheroid, or an ellipsoid of revolution whose axis coincides with the vertical crystallographic axis, that is, the optic axis. In the direction of the vertical axis it would vary that the wave-fronts of the ordinary and extraordinary rays will coincide.

Figs. 582 and 583 represent various sections of the combined wave-surfaces for both rays. Fig. 582 gives that for a negative crystal ($\omega < \omega'$), the ellipsoidal wave-surface of the extraordinary ray being outside the spherical surface of the ordinary ray, Fig. 583 that of a positive crystal like quartz ($\omega < \omega'$) with the ellipsoidal surface within that of the sphere. Fig. 584 is an attempt to show the relationship of the two wave-fronts of a negative crystal in perspective, for a single crystal. For constant value of the velocity of the ordinary ray ($\frac{1}{\omega}$), whatever its direction in the plane of Figs. 582 and 583 is expressed by the radius of the circle OC . On the other hand, the velocity of the extraordinary ray in horizontal direction is given by OA ($\frac{1}{\omega'}$), while in any other direction, as OC' (Fig. 582) or C' (Fig. 583), it is

expressed by the length of this line, becoming more and more nearly equal to $OC' \left(\frac{1}{\omega} \right)$ as its direction approaches that of the vertical axis.

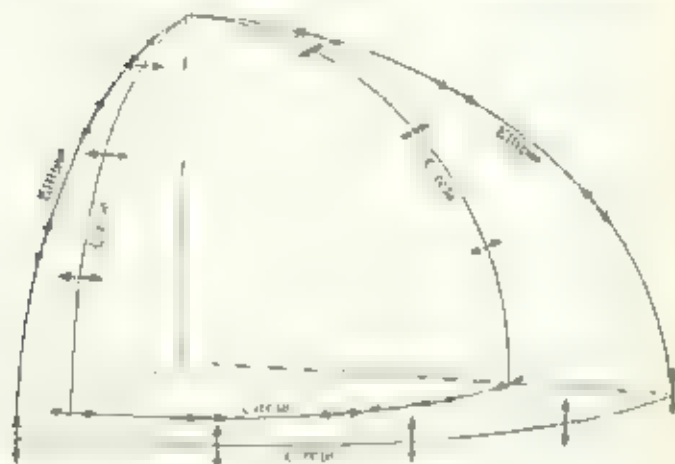
582

Negative crystal, $c < \omega$

583

Positive crystal, $\omega < c$

584



390 Uniaxial Indicatrix. - The optical structure of a uniaxial crystal can be represented by an ellipsoid of revolution, called the *indicatrix*,* from which can be obtained the directions of vibration and indices of refraction of the ordinary and extraordinary rays derived from any single incident ray. Fig. 585 represents a principal section of such an ellipsoid for an optically negative crystal, the line OC' being its axis of revolution. The axes of this ellipsoid are made inversely proportional to the indices of refraction of the two rays, ω and c , as follows:

$$OC : OA = \frac{1}{\omega} : \frac{1}{c} \quad \text{or} \quad c : \omega.$$

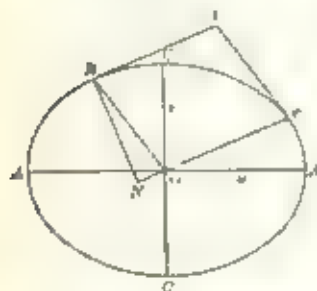
* The Optical Indicatrix and the Transmission of Light in Crystals, by L. Fletcher (London, 1902).

In this figure let Or be a direction of transmission of light. Let Vr and VR be tangents to the elliptical surface at point r and k and OR be a radius vector parallel to the tangent Vr . Or and OR then will be known as *conjugate radii*. From the geometrical properties of an ellipse it follows that the area of any parallel gram with conjugate radii forming as sides such as OR , Vr in fig. 585, is constant and equal to the area of a parallel-gram having OR' and OA as two sides. Let RN be perpendicular to the extended line Or . Then the area of ORR' will be equal to $RN \cdot Or$. It follows since $RN \cdot Or = OA \cdot OR = \text{constant}$, that

$$Or = \frac{OA \cdot OR}{RN} = \frac{k}{RN}; \text{ also } OA = \frac{k}{OR}.$$

From the last expression, we see that OA and OR' are inversely proportional to each other. In other words, as OR represents the transmission index OA will

585



represent the corresponding velocity of light which will be the maximum for any transmission direction in the crystal. In the same way Or and RN are inversely proportional to each other the distance Or representing the velocity of the extraordinary ray traveling along that direction while RN will represent its refractive index. The line RN will also give the direction of vibration of the extraordinary ray.

For the radius vector Or there will be another possible direction perpendicular to it and also normal to the elliptical surface. This will be a line from O perpendicular to the principal section represented in fig. 585. This line will

be in the horizontal circular section of the indicatrix and parallel with its length equal to OA which in turn is proportional to the index of the ordinary ray ω . So, for a given direction of transmission of light and as Or the two lines that are perpendicular to r and at the same time normal to the surface of the indicatrix yield with the squares of refractive index of the two rays and the directions of their vibrations.

If, however, the light is passing parallel to the principal axis of the indicatrix, i.e., OA in fig. 585, there will be an infinite number of lines which are perpendicular to this direction and at the same time normal to the surface of the indicatrix. These will be all the circular circular sections of the ellipsoid and consequently will be of a uniform length. From this it is evident that such a transmitted ray may vibrate in any transverse direction and will possess a single index of refraction and velocity. Along this direction, known as the optic axis, there will consequently be no double refraction of the light.

361 Examples of Positive and Negative Crystals. The following lists give prominent positive and negative uniaxial crystals with the name of the refractive index, ω , and ϵ of each illustrating ω and ϵ as used in fig. 585. The difference between these, $\omega - \epsilon$ or $\epsilon - \omega$ as the case may be, measures the anisotropy or strength of the double refraction.

It may be remarked that some species such as and varieties have been observed certain crystals of graphite are positive (for carbon) of the spectrum of light, or for the other, and consequently for some color between the two extremes. There is no double

refraction. The same is true for some other species, e.g., chalcidites of weak double re-

NEGATIVE CRYSTALS

	n_o	n_e	$n_o - n_e$
Pyrope	2.070	2.711	0.641
Calcite	1.658	1.486	0.172
Tetrahedrite	1.935	1.670	0.265
Calcium	1.705	1.600	0.105
Ilmenite	1.980	1.780	0.200
Amphibole	1.730	1.715	0.015
Neubergite	1.912	1.838	0.074
Apatite	1.631	1.631	0.000

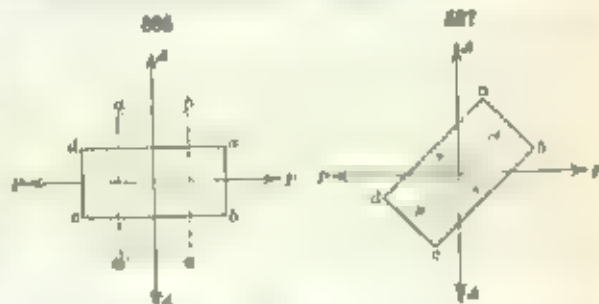
POSITIVE CRYSTALS

	n_o	n_e	$n_e - n_o$
Ilmenite	1.980	2.003	0.023
Calcite	1.658	1.688	0.030
Zircon	1.921	1.968	0.047
Quartz	1.559	1.580	0.021
Phenacite	1.634	1.670	0.036
Quartz	1.544	1.553	0.009
Spinel	1.508	1.509	0.001

Examination of Uniaxial Crystals in Polarized Light

392. Section Normal to the Axis in Parallel Polarized Light. Suppose a section of a uniaxial crystal to be cut perpendicular to the vertical crystallographic axis. It has already been shown that light passing through the crystal in this direction suffers no double refraction, consequently such a section examined in parallel polarized light behaves as a section of an isotropic substance. If the nicols are crossed it appears dark, or, being asked, and remains so when revolved.

393. Section Parallel to the Axis. A section cut parallel to the vertical axis, as already explained, has two directions of light vibration, one parallel to this axis, that of the extraordinary ray, and the other at right angles to it, that of the ordinary ray. A ray of light falling upon such a section with perpendicular incidence is divided into the two rays, ordinary and extraordinary, which travel on in the same path through the crystal,



but one of them retarded relatively to the other. When such a section is examined in polarized light with crossed nicols it will appear dark, or be extinguished when its vibration direction is parallel to the vibration directions of the nicols. Assume that the section used Fig. 586 lies with the direction of its vertical crystallographic axis parallel to P^*P , which represents the vibration direction of the polarizer. The light entering the section under these

conditions will be vibrating parallel to the vertical axis of the crystal and will therefore pass into the analyzer, wholly as the extraordinary ray, there being no variation possible in the direction of the ordinary ray. The light will, therefore, move the section with the same direction of vibration as when it entered and will be entirely lost by extinction in the analyzer. If the section is turned at an angle of 90° as in Fig. 586, similar vibrations prevail, although in this case the light will vibrate in the section as the ordinary ray. Therefore, if such a section there will be light passing during its complete revolution to the stage of the polariscope or microscope when it will be extinguished.

If the section stand obliquely as shown in Fig. 587, it will appear light to the eye and usually colored, for the vibrations parallel to P that have passed through the polarizer have their resolution a component in the direction of each of the vibrations axes of the section. Again, each of these components can be resolved along the direction of the vibration plane of the analyzer, A . Therefore, two rays will emerge from the analyzer, both having the same vibration plane, but one more or less colored with reference to the amount of retardation increasing with the birefringence and the thickness of the section. In general, therefore, these rays will interfere, and if the thickness of the section is sufficient (and not too great), it will appear colored in white light and, supposing the thickness and n , of the same color throughout.

394. Parallel Extinction.—When the vibration directions of a section coincide with those of the polarizer and analyzer, setting them 90° as usual, the section appears dark and is said to be in the position of *parallel extinction*. If a section, extinguished when a crystallographic axis or crystallographic plane of one of the planes of vibration of the axes is used to show *parallel extinction*. If on the contrary, the section shows colors when the crystallographic directions are the directions of vibration of the analyzer and polarizer, it is said to show *inclined extinction*.

In the case of uniaxial minerals, since the vibration directions always lie in some crystallographic plane, the sections of such minerals will show *parallel extinction*.

395. Determination of the Relative Character of the Extinction Directions of a Given Uniaxial Mineral.—The relative characters of the extinction directions of a section of a uniaxial mineral are to be determined by the use of the optician's wedge or the sensitive tint as described in Art. 384. If the orientation of the section is known, we then at once tell which of the directions of vibration belongs to the ordinary and which to the extraordinary ray the positive or negative character of the axes can be determined. For instance, if the ordinary ray is proved to be the faster of the two, i. e., the λ direction, it follows that the index is the smaller, i. e., $\omega < \epsilon$ and the mineral is positive.

396. Interference Colors of Uniaxial Minerals. Birefringence.—The interference color of any section of a uniaxial mineral depends upon the following: first upon the thickness of the section second upon the strength of the double refraction of the mineral, i. e., its birefringence, this being measured by the difference between the indices of refraction of the two rays in the section and third upon the crystallographic orientation of the section. A section cut parallel to the basal plane shows the least retardation and therefore cannot exhibit any interference color. The strength of the birefringence, the other

opacity remaining uniform, increases as the inclination of the section to the basal plane increases. The highest birefringence of a given mineral is therefore shown by its prism cut sections.

The following table* gives the thickness in millimeters of sections of a few common crystals which yield red or the like color.

	Birefringence $n_e - n_o = \Delta$	Thickness in Millimeters
Rutile	0.287	0.0010
Calcite	0.172	0.0032
Zircon	0.062	0.0080
Leucosaphire	0.021	0.0240
Quartz	0.009	0.0612
Nephelite	0.004	0.1577
Leucite	0.001	0.5510

Again, as another example of this, an optician cut with a gem $n_e - n_o = 0.002$ a thick-ness of $\frac{1}{2}$ inch will give red of the first order, of 0.01 inch of the same order of opacity will be too thin.

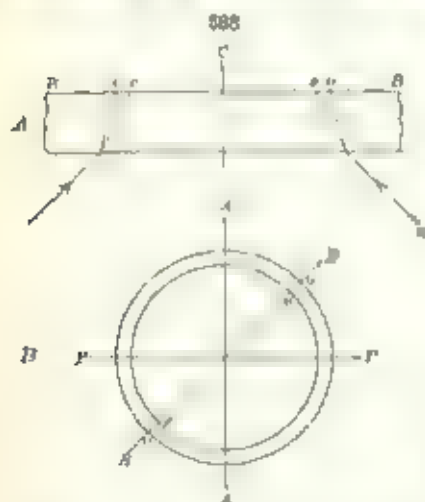
The thickness of a crystal used to determine the birefringence of a section is not a new thing. It is a well-known fact that crystals are refractive media of two very different orders of magnitude, see Arts 353 and 364.

397 Effects of Convergent Polarized Light upon Sections of Uniaxial Minerals. Uniaxial Interference Figures. When certain sections of uniaxial minerals are observed in convergent polarized light they show what are known as *interference figures*. A symmetrical interference figure is obtained in uniaxial minerals by allowing converging polarized light to pass through a thin section of the crystal. Parallel polarized light entering such a section would suffer no double refraction, and consequently give no interference. To convert the parallel polarized light that comes from the polarizer into convergent light it is required that between the polarizer and the section, under these conditions, a sharply converging cone of light rays enters the section. Another end is placed above the section to change these divergent rays back again into a parallel position. Such an instrument is known as a *conoscope*. It may be composed of a pair of lenses between the polarizer and analyzer of a polariscope, or because the polarizing prism is used, the small converging lens that lies above the polarizer is acting in a position by a lens and by the small tube is analogous known as the Bertrand lens is introduced into the conoscope tube.

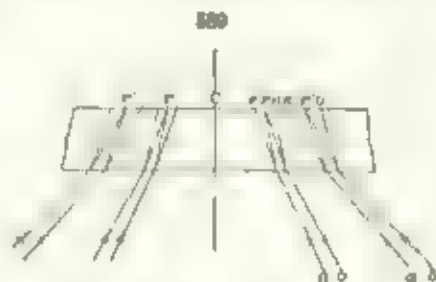
In order such observations the light entering the section is composed of a converging system of rays polarized and vibrating in the plane $P'P'$, Fig. 588. Let $B-B'$, Fig. 588, to be a vertical cross section of the uniaxial section along the line $B-B'$, Fig. 588 B' . Consider any ray unit entering the section. Since the ray enters a section of uniaxial it will be doubly refracted into the rays e and o . The uniaxial being taken as indicate the extraordinary ray, indicate being negative will have the greater velocity and be less refracted. As the light enters the section in the form of a cone the traces of the two rays as they emerge from the section will be circles, Fig. 588 B' . Now consider the rays e and o emerging from the section of the two rays a and b or a' and b' , Fig. 589, upon the other. Rays e on entering the section is doubly refracted and polarized into the rays e and o which are considered as emerging from the section at the

* see further, Rosenbach (Mikr. Phys. Min., 1904, p. 292) from whom these are taken.

points *e* and *r*. Ray *b* also on entering the section is doubly refracted and polarized. Suppose the extraordinary ray derived from *b* emerges from the section at the same point as the ordinary ray derived from *a*, that is at *r*. Since it travels with a greater velocity the extraordinary ray emerging at this point will have advanced in its phase over that of the ordinary ray. In that case they would be in a condition to interfere with each other except that they are vibrating in planes perpendicular to each other and so cannot. The two rays travel on, vibrating in planes at right angles to each other and, maintaining this difference in phase until they reach the upper Nicol, there they are each resolved into rays vibrating in the plane *A-A*, fig. 588 *II*, and now ray in condition to interfere with each other. Let us be assured that the conditions are right for the extraordinary ray to emerge from the section just one wavelength ahead of the ordinary ray. Its *x* components in the upper Nicol will have opposite phases and therefore compensate each other, see Art. 341. If the section is viewed in a monochromatic light of *x* distance,



the conditions are right for the extraordinary ray to emerge from the section just one wavelength ahead of the ordinary ray. Its *x* components in the upper Nicol will have opposite phases and therefore compensate each other, see Art. 341. If the section is viewed in a monochromatic light of *x* distance,



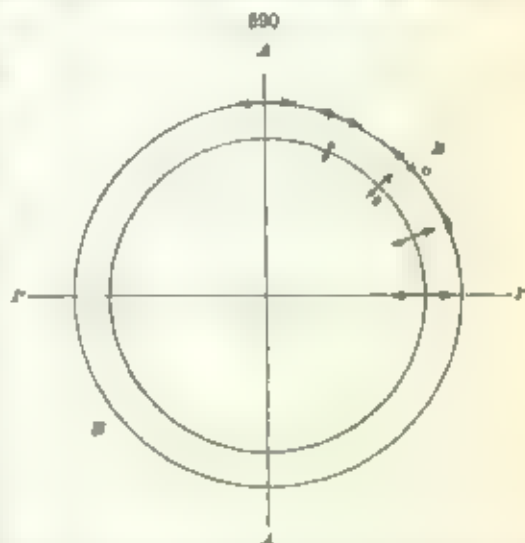
sodium light this interference will result in a black point. But as these rays are converging in the form of a cone they will make when they strike the section a circular trace upon its surface and their interference will result in a dark ring. Going out from the center of the section there will be a succession of these rings corresponding to the interference of waves 1, 2, 3, 4, 5, etc., wavelengths apart. As the distance from the center of the section is increased, the paths of the refracted rays in the section are lengthened and the points of interference are brought closer together. This will cause the interference rings to lie nearer together as the distance from the center of the figure increases.

Fig. 590 is a top view of the section without taking into consideration the effects of the upper Nicol. Let the two circles represent the traces of the emergence of the two rays *e* and *r* into which the incident conical ray is divided, *e*, being the ray refracted (for calcite), will be the inner one. The plane of vibration of *e* is always parallel to some plane passing through the vertical axis of the crystal therefore the trace of its plane of vibration upon the surface of the section will always be in a radial direction. The plane of vibration of *r* is at right angles to that of the extraordinary ray and parallel to the horizontal axes of the crystal, therefore the trace of its plane of vibration

upon the surface of the section will always be in a tangential direction, see Fig. 500. Along the line $P-P$, Fig. 500, only light vibrating in a radial plane or out of the extraordinary ray can come through the section, since the light entering the section cannot be resolved into the vibration of the ordinary ray. The intensity and direction of vibration of the light that emerges from the section along the line $P-P$ is represented by the double arrow on that line. Along the line $A-A$, since the light entering the section is still vibrating in the plane $P-P$, all the light passing through the section must vibrate as the ordinary ray. It is evident, therefore, that along these two directions, $P-P$ and $A-A$, the plane of vibration of the light is not changed by passage through the section and consequently such light will be completely absorbed in the upper Nicol. In this way dark lines will be formed along the lines $P-P$ and $A-A$. These dark areas along which extinction occurs are known in both the uniaxial and biaxial interference figures, as *isogyres*. A dark spot will also be formed in the center of the field because any light entering the section at this point must enter in the direction of the optic axis and therefore will not be doubly refracted and consequently will also be absorbed in the analyzer.

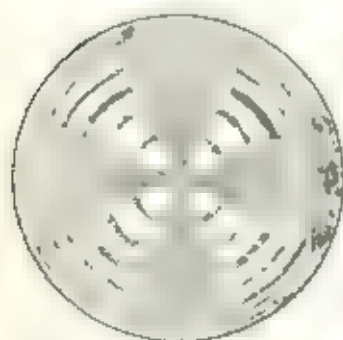
Now consider point B , Fig. 500, which lies 45° away from P and A . Here the directions of vibration of e and o would be equally inclined to the planes of vibration of the polariscope, $A-A$ and $P-P$. Light striking the section at B would be vibrating in the plane $P-P$ but by resolution a component vibrating in the direction $B-B$ would come through the section as the ray e , in the same manner a component vibrating in a direction at right angles to $B-B$ would emerge as o . The intensities and directions of vibration of these two rays at this point are represented by the double arrows. When these rays meet the analyzer above they would again each be resolved and their components which vibrate in the plane $A-A$ would emerge from the analyzer. In this way it is seen that, except at the special points where complete interference takes place, light will result in the interference figure at all points away from the center of the figure and from the lines $P-P$ and $A-A$. From the consideration of Fig. 500 it is evident that the greatest amount of light will come through the section at the 45° points, such as B . When viewed in monochromatic light, therefore, the interference figure consists of a series of concentric dark and light rings crossed by a vertical and a horizontal brush intersecting in the center of the field of the microscope, like Fig. 501.

If a thin section of a uniaxial mineral while in the conosccope is viewed in



the light-colored rings will take the place of the light and dark rings observed in the uniaxial mineral light. The change will be like that shown by the quartz wedge in the similar case described in Art. 349. Where the first few dark rings near the center of the figure were formed by the interference of rays having the wave-length of some of the light-colored rings will result in the bright interference. These rings will be composed of all the components of white light with the yellow of sodium subtracted. The other colors are obtained in a similar manner by the combination of single interferences of some particular wave-length of light. While the interference figure is examined in the microscope the light showed a large number of distinct black rings at first, and the corresponding colored rings are in 180° in number, and their colors gradually becoming fainter as the distance from the center of the figure increases, finally merge into the white of the light color. This is due to the overlapping of the interference rings of the various colors in the same manner as observed in the quartz wedge (see Art. 349). The interference figure viewed in daylight will of course retain the black cross in the center since these are due to the cutting out of all the light by the analyzer and is not the result of interference.

581



Uniaxial Interference Figure

will give a certain amount of retardation or a color wash. The nearer the circles will be to the center, further for the same section, the circles will be more numerous than for red, on account of their shorter wave-length. When the plate is of greater thickness or of greater thickness only the black hues will be distinctly seen.

398. Determination of the Positive or Negative Character of the Birefringence of a Uniaxial Mineral from Its Interference Figure

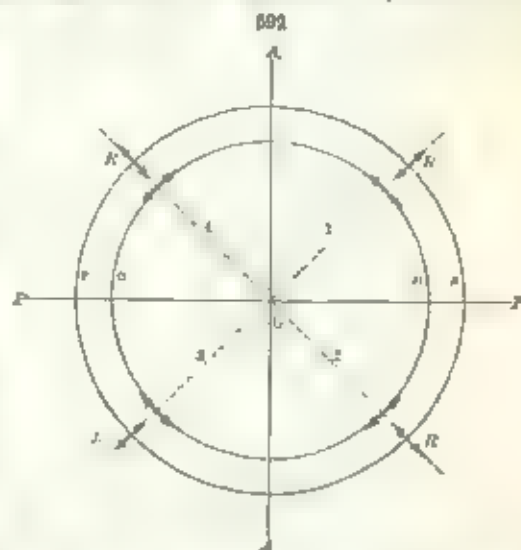
Use of the Maltese Cross. For the determination of a uniaxial mineral it is absolutely important to determine whether the character of its birefringence is positive or negative. This can usually be best ascertained by first examining the interference figure. One of the most convenient ways of making this test is by the use of a small microscope which is moved so that that of the two rays of light passing through the one has passed one quarter of a wave-length in phase over the other. The mica is usually placed between one of the narrow glass plates and is known as the one plate wave-length mica plate. The constantly marked Z with an arrow indicating the Z optical direction. It shows an interference figure by means of the mica plate the latter is inserted somewhere between the polarizer and analyzer in the microscope can easily through the slot just above the object and now oriented that the Z direction makes an angle of 45° with the plane of vibration of the mica.

In Fig. 392 let $P-P'$ represent the plane of vibration of the polarizer and $A-A'$ the plane of vibration of the analyzer of a microscope. Let O be the

point of emergence of the optic axis of a positive uniaxial mineral. Suppose a single circular ray of light enters the section. It is broken up in the mineral into two rays, o and e which emerge from the section along the arcs of the circles shown in Fig. 502. The arc of the ordinary ray, o , will be within that of the extraordinary ray, e , because in a point very near the o ray travels faster and is less refracted. The directions of vibration of these two rays at the points R and R' are represented by the double-headed arrows. When these rays reach the analyzer they will be resolved into components vibrating parallel to A . There are in it quite a number of such rays entering and proceeding through the mineral section with varying angles of inclination and therefore varying lengths of path. At some certain distance from the center the rays will emerge on the same circle with a difference of phase of one whole wave-length and when resolved in the upper Nicol into rays vibrating in the same plane will interfere with each other and produce the first dark ring of the interference figure as it is viewed in monochromatic light.

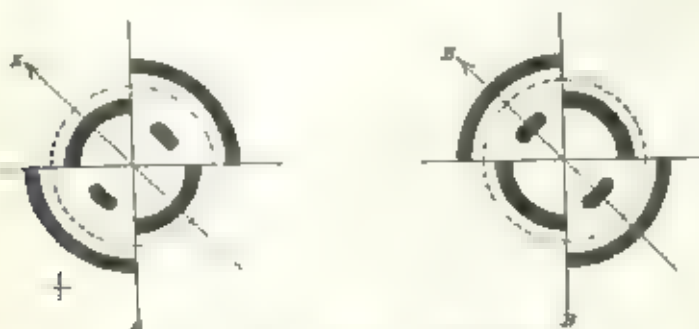
If the mica plate is introduced above the section a change in the interference figure is noted. The optical character of the mica cannot be fully explained at this point. It is sufficient for present purposes to know that it is a doubly refracting mineral which breaks light up into two rays which are polarized in planes at right angles to each other and which, traveling with different velocities through the mica, will emerge from it with different phases.

As stated above the mica plate is placed in the requisite thickness so that the two rays emerge from it with a difference of phase of one quarter of a wave-length. Consider what takes place when such a plate is introduced above the section represented in Fig. 502 in such a position that its vibration direction Z is parallel to the direction $R-O-R'$ of the figure. Consider what takes place at the points R . Then the vibration direction of the e ray coincides with the vibration direction Z of the mica plate. These vibration directions in each case are those of the rays traveling with the smaller velocity. On the other hand, at the same point the vibration direction of the o ray in the mineral coincides with the vibration direction X in the plate, both of these being of the rays with the greater velocity. So at this point the effect of the mica plate is to increase the difference of phase between o and e and to produce the same result as if the mineral section had been thickened. Consequently the interference rings along the line $R-O-R'$ are increased in number and drawn toward the center of the figure. At the points R' the opposite is true. The vibration direction of e coincides now with that of X in the mica plate; the



direction of less velocity in the mineral with that of the greater in the mica. Also the vibration direction of e coincides with that of Z , that of the greater velocity in the mineral with the less velocity in the mica. So at this point the mica will decrease the difference in phase between e and e' and produce the effect of thinning the section and so spreading the interference rings farther apart along the line $R-O-R'$. In quadrants 2 and 4, therefore, the rings will be drawn nearer the center, while in quadrants 1 and 3 they will be pushed farther out. Another effect caused by the insertion of the mica plate is even more pronounced. In quadrants 1 and 3, at the center illustrated in Fig. 592, black dots were present near the center of the figure. In the interference figure, before the introduction of the mica plate, there were points in quadrants 1 and 3 at short distances from the center, O , where the two rays, e and e' , emerged from the section with a difference of phase of one quarter wave-length. Under these conditions no interference could take place and these spots were light. The effect of the mica plate in these two quadrants is everywhere to reduce the birefringence due to the mineral by one quarter of a wave-length.

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Determination of Optical Character with Mica Plate

Therefore at these two points the difference of phase caused by the birefringence of the mineral is annulled by the mica plate and consequently at these points interference will result and black dots appear. The mica plate produces similar effects. The brushes which were dark in the interference figure become light. Light coming from the crystal section along the lines of the brushes is vibrating only in the vibration direction of the prism and ordinarily is wholly cut out by the analyzer above. But with the mica plate intervening this light is broken up in the mica into two rays which vibrate in the vibration planes of the mica and as these are normal to the plane of the analyzer a portion of the light will come through to the eye. As the light coming from the section along the lines of the brushes had only a single velocity (was entirely either the ordinary or extraordinary ray) there are only two rays emerging from the mica plate along these directions and their difference of phase is one quarter of a wave-length. Under these conditions there can be no interference and white brushes result. In the same way the dark center of the interference figure becomes light.

Fig. 593 A is a diagrammatic representation of the interference figure of a positive mineral as affected by the insertion of the mica plate, the direction

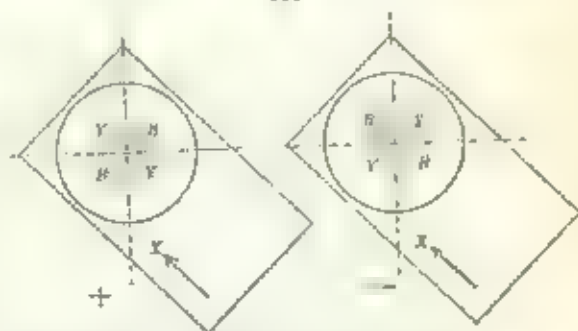
of the arrow indicating the direction Z of the mica, i.e., the direction of vibration of the ray having the smaller velocity. In the case of a negative mineral the characters as described above will be completely reversed. Fig. 592, represents the appearance of an interference figure of a negative mineral when the mica plate is used.

Therefore, to determine the optical character of a uniaxial mineral from its interference figure insert a mica plate above the section with the Z direction running 45° with the vibration planes of the mica. Then, if the direction Z is at right angles to a line joining the two black dots that appear near the center of the figure (i.e., the two lines form a plus sign), the mineral is positive; if, on the other hand, these two directions coincide (form together a minus sign) the mineral is negative.

Use of the Sensitive Tint.—The sensitive tint, see Art. 350, is used to determine the positive or negative character of a uniaxial mineral from its interference figure when the mineral section is so thin, or the mineral possesses such a low birefringence, as to show in the figure only a thick cross without any rings. Under such conditions the mica plate would not give a decisive test. The sensitive tint is usually so mounted that its longer direction coincides with the direction of the faster ray, i.e., the direction Y . The sensitive tint is introduced somewhere between the polarizer and analyzer in such a position that its vibration directions are at 45° with the planes of vibration of the mica. Let it be assumed that we have the interference figure from a positive mineral, such as is represented in Fig. 592. If the sensitive tint is introduced in such a position that its Y direction is parallel to the line $R-O-R$ the X direction of the sensitive tint will be parallel to the direction of vibration of the ray in the mineral. Since the mineral is positive the x ray will have the smaller velocity and, therefore, in quadrants 2 and 4 the optical orientation of the mineral and the sensitive tint will be opposed to each other. The sensitive tint alone would produce an interference color of *red* of the first order. But if the effect of the birefringence of the mineral is such as to subtract from the birefringence of the sensitive tint the color will change to *yellow*. Consequently in these quadrants yellow spots will appear near the center of the field at the points where the effect of the mineral has been sufficient to lower the interference color to that extent. In the other quadrants 1 and 3, the faster and slower rays of the mineral and sensitive tint coincide in their directions and the effect of the two substances is additive. Consequently in these two quadrants the color will rise to *blue*.

In making the above test with the sensitive tint it is convenient to follow the rule that if the direction X of the sensitive tint crosses a line joining the two blue dots (makes a plus sign) the mineral is positive, if, on the other

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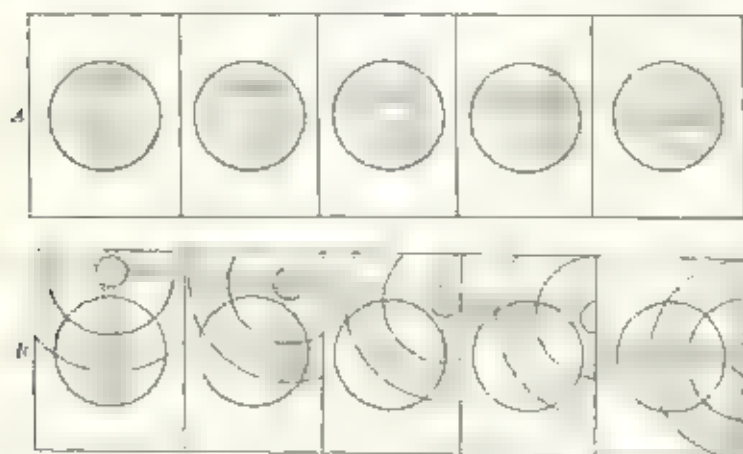
Determination of Optical Character with Sensitive Tint.

rand, these two directions coincide (make together a minus sign) the mineral is negative. These conditions are illustrated in Fig. 594.

399 Interference Figures from Inclined Sections of Uniaxial Minerals.

It frequently happens that a mineral section under observation for an interference figure is not cut exactly parallel to the basal plane of the crystal. An interference figure obtained from such an inclined section will, of course, be concentric to the microscope field. If the section is inclined only a little to the basal plane, the center of the figure, i.e., the point of emergence of the optic axis will still be within the field of vision, and will move in a circle about the center of the field when the section is revolved upon the microscope stage (Fig. 595 A), showing the successive positions of such an interference figure during revolution. If the section is more sharply inclined the center of the interference figure may be quite outside the field. As the section is turned on the

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Eccentric Uniaxial Interference Figures

stage the four arms of the interference cross will traverse the field in succession. They will move across the field in a straight line and provides no section. A section cut not too highly inclined to the optic axis will move a circle the field, parallel to the cross-arms of the microscope. This fact is of importance up to the microscope, since a uniaxial interference figure from a crystal section, figure. This latter will often show similar lines which, however, will merely curve as they cross the field of the microscope. If the first of these lines or the cross-arms moves from left to right across the field, the second will move from the top to the bottom, the third from right to left, and the last from the bottom to the top, etc. Fig. 595 B, shows the different positions of such a figure during one quarter of a revolution. If the section is even more highly inclined to the optic axis the black bars in the figure will show some curves, as they move across the field during the rotation of the section. They will cross the center of the field in straight lines being parallel to either the horizontal or vertical cross-arms of the microscope, but as they depart from view the end away from the optic axis, which will be broader and more vague

in its centre, will curve slightly, bending away from the cross-hair to which the bar as a whole is parallel.

The positive or negative character of the mineral can usually be determined from an eccentric figure if care is taken to make certain which quadrant is darker when the test is made. For instance, in Fig. 596 is shown how the test is made with the sensitive tint upon the eccentric interference figure of a positive mineral.

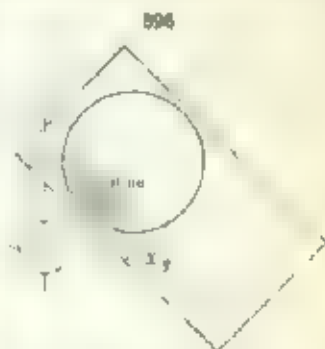
In examining unoriented sections of a mineral, such as the random sections found in a rock specimen or the small fragments of a mineral placed upon a glass slide, it is necessary always to find that section that gives the lowest interference color. The amount of birefringence shown in various sections of a uniaxial mineral increases as the section is perpendicular to the orientation of the basal plane. Consequently that section showing the lowest interference color will yield the most nearly symmetrical interference figure.

400. Interference Figure from a Prismatic Section of a Uniaxial Mineral.

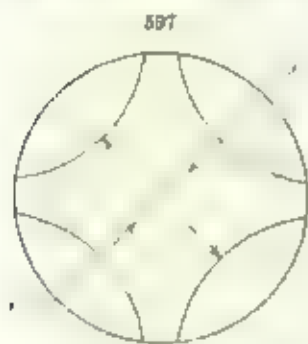
When a prismatic section of a uniaxial mineral is examined for an interference figure the result is a figure which is analogous to that obtained in the case of biaxial crystals. The reasons for this resemblance will be pointed out in a later article. The two types of figures cannot be in this case easily differentiated. Two dark and usually well-defined hyperbolas approach each other as the section is turned in the proper

sense, stop short at a point, cross, and then separate and disappear. For this reason the figure is often called a "dash figure." These differ from those obtained in an ordinary biaxial interference figure in that they run only as far as they move away from the crossed position. These figures are always symmetrical about the line that represents the axial section of the crystal. As the position of the section is varied, the field quickly shows interference colors arranged in a pattern similar to that observed in Fig. 597. The outline and position of the hyperbolas of the axes of the crystal (see Fig. 596) will become

those of opposite quadrants in which the colors had their order in passing away from the center of the field. If it is possible to make definite observations, this fact alone on the prismatic section can be determined and then by means of a plane-polarized light the positive character of the mineral and extinction angle (which can be determined on the crystal) give it a mineral. It must be emphasized, however, that confusion can easily exist between the figure and a similar one obtained from certain sections of a cubic crystal (see Art. 417). No type of uniaxial figure can be easily obtained from the quartz wedge.

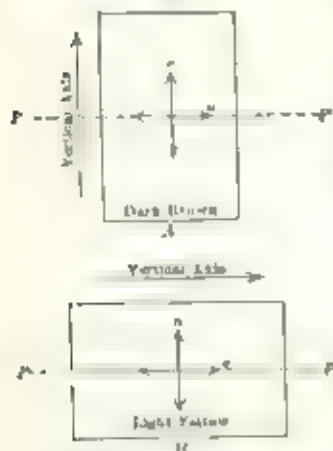


Sensitive Tint with Eccentric Interference Figure



401. Absorption Phenomena of Uniaxial Crystals. Dichroism. When light enters colored minerals as rays of white light, i. e., containing vibrations of all wave-lengths from that of violet light at one end of the spectrum to that of red light at the other, certain wavelengths will be absorbed during the passage of the light through the mineral, so that the light as it emerges, has a definite color. It happens in certain deeply colored minerals that the amount and character of this absorption depends upon the direction of the light vibrations. For instance, in the case of malachite minerals, the ordinary and extraordinary rays may emerge from the section with distinct different colors. Take, for instance, a prismatic section of a brown colored tourmaline and observe it in plane polarized light without the use of the tourmaline. As the section is revolved upon the stage of the polariscope the color may change from a dark brown to a light yellow-brown. The greatest difference in the

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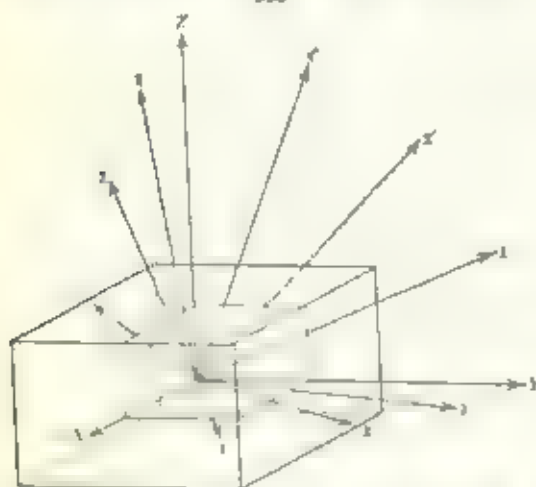


color occurs at points 90° apart, at which the crystallographic directions of the section, i. e., the vertical crystallographic axis and the trace of the plane of the horizontal axis are either parallel or perpendicular to the vibration plane of the polarizer. In other words, these extremes of color occur when the directions of the vibration of the ordinary and extraordinary rays in the section are parallel or perpendicular to the vibration plane of the light entering the section. In Fig. 594 A, let $P-P'$ represent the vibration direction of the light entering the section. The mineral section is so placed that the direction of the vertical crystal axis is perpendicular to $P-P'$. The light on entering the section will, therefore, vibrate in the plane of the horizontal axis or as the ordinary ray. In this position the tourmaline section is dark colored, and consequently it is seen that light vibrating in the mineral as the ordinary ray is largely absorbed. Now turn the section through 90° so that the position shown in Fig. 594 B. In this position the light must vibrate in the section wholly as the extraordinary ray, e , and the color is a light yellow-brown. Therefore the extraordinary ray is only slightly absorbed. The difference in the absorption or the color of the two rays is known as *dichroism*. Either the ordinary or the extraordinary ray may be the most absorbed, and the two cases are expressed as either $e > o$ or $e < o$ or $e = o$. In uniaxial minerals dichroism is to be best observed in prismatic sections where it attains its full intensity. Bowed sections show no dichroism since light passing through the section parallel to the optic axis must all vibrate in the horizontal axis plane and belong wholly to the ordinary ray.

An instrument called a *dichroscope* contrived by Haidinger is sometimes used for examining thin sections of crystals. An oblong thin section of lithium spar is placed in a suitable vibration plane, having a cross at one end, and a vertical line at the other. On looking through it the section here appears as two images because of the ordinary ray as the other to the extraordinary ray. When viewed between two crossed nicols the two images and light on the e and o rays are two squares at intervals of 90° and the two images have different colors. For example, the vibration o of the e ray and extraordinary ray in calcite. Since the two images are situated side by side, a very slight

assumed differences in the ether along them. The nature of these three directions is as follows: Light which results from vibrations parallel to X (axis of greatest elasticity) is propagated with the maximum velocity, that from vibrations parallel to Z (axis of least elasticity) with minimum velocity, and that from vibrations parallel to Y with an intermediate velocity. It is to be emphasized that these directions, X , Y , and Z refer to directions of vibration at right to direction of propagation. Corresponding to the various ether-mechanisms and ether-mechanic velocities are, for convenience, the usual indices of refraction designated respectively as α , β , and γ *, which may be designated as N_x , N_y , and N_z . Of these α , belonging to light with the maximum velocity, will have the least value, and γ belonging to light with the minimum velocity, will have

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the greatest value. The value of β will be intermediate between the other two, sometimes being nearer to α and at other times being nearer to γ ; it is not the arithmetical mean between them. The various methods of determining the values of these three principal indices of refraction will be considered in a later article.

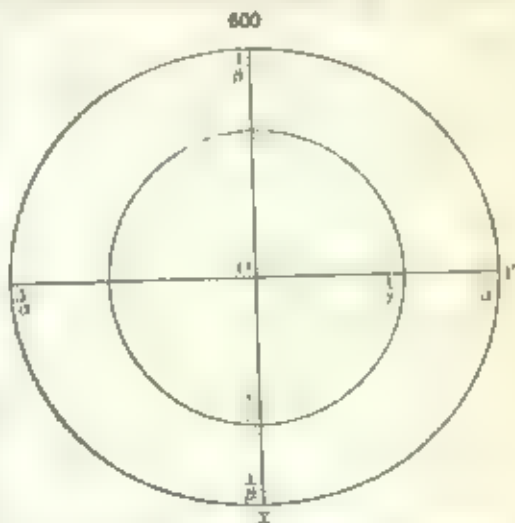
In studying the propagation of light within a biaxial crystal, let it be assumed that fig. 590 represents a rectangular parallelepiped in which the front to back axis is the direction X , the left to right axis is Y , and the vertical axis is Z . In

connection with this figure and those which follow it is important to make use of a small convention which would answer somewhat as the letters a , b , and c do in a rectangular prism, to indicate that X is front to back, Y is left to right, and Z is up and down. The various directions of vibration X , Y , and Z are those of the figure. In the description of this figure and following it, it is to be assumed that the three principal indices of refraction are 1.5 , 1.6 , and 1.75 , the difference between α and γ far exceeding anything observed in actual crystals. To point out the difference, as to axes of the crystal, it is necessary to exaggerate the α and γ values greatly, and β then. The phenomena may be diagrammatically shown by diagram 590, as follows:

In the discussion that follows it will be assumed that light originates at the center of a crystal (O , fig. 590), and the observer will be made to determine the character of the rays which radiate from O in a direction AO . The various directions, and the ones which in reality are the most important, are those that are in the axis planes of the figure, XOY , YOZ , and XOZ . These will be considered first.

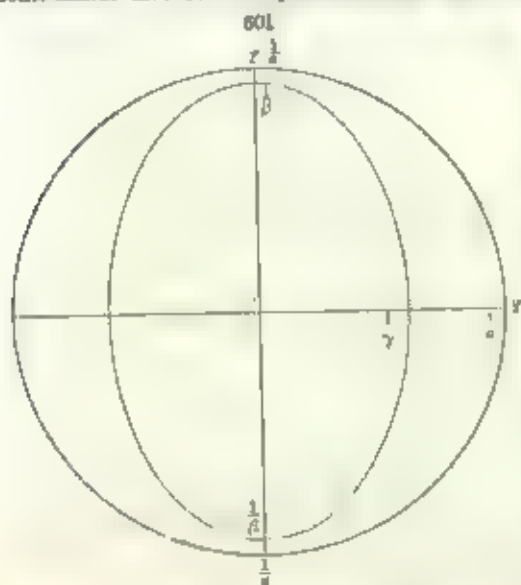
* Since the α , β , and γ are used to designate α , and γ not only to indicate the three principal directions of vibration, but also the vibration directions of light (i.e., X and Z), can correspond to these indices.

Consider the plane of the X and Y directions, Fig. 500. Light will radiate from O toward X and Y and in all intermediate directions with vibrations parallel to Z and hence traveling with a uniform and at the same time minimum velocity, $1/\beta$. The distance such light will travel in a given moment of time may be plotted by drawing a circle about O with the radius $1/\gamma$, Fig. 600. In the direction OX there must also travel a second polarized ray resulting from vibrations parallel to OY hence traveling with intermediate velocity $1/\beta$. Likewise in the direction OY there will be a ray resulting from vibrations parallel to OY hence traveling with the maximum velocity $1/\alpha$. In all directions intermediate between X and Y the light velocities will be proportional to the radii of an ellipse having $1/\beta$ and $1/\alpha$ respectively as its semi-minor and semi-major diameters, Fig. 600.



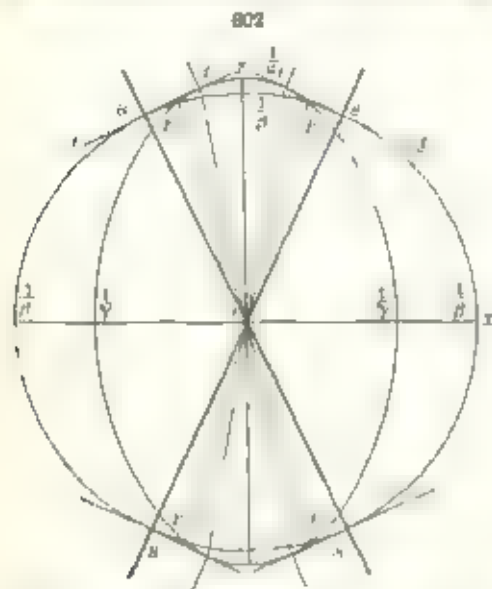
In the plane of the X and Y directions, therefore, in a given moment of time light will radiate from the center as ordinary and extraordinary rays, the wave-fronts being represented by a circle within an ellipse.

Consider next the plane of the Y and Z directions, Fig. 501. Light will radiate from O toward Y and Z and in all intermediate directions resulting from vibrations parallel to OY . It will therefore travel with uniform and the maximum velocity, $1/\alpha$. The distance traveled in a given moment of time may be plotted by drawing an ellipse about O with the radius $1/\alpha$, Fig. 601. Likewise there will travel in the direction OY a second ray resulting from vi-



butions parallel to OZ hence moving with the minimum velocity, $1/\gamma$. Also in the direction OZ there will be a ray resulting from vibrations parallel to OY with the velocity $1/\beta$. In directions intermediate between Y and Z

the light velocities will be proportional to the radii of an ellipse having $1/\gamma$ and $1/\beta$ respectively as its semi-minor and semi-major diameters Fig. 601.

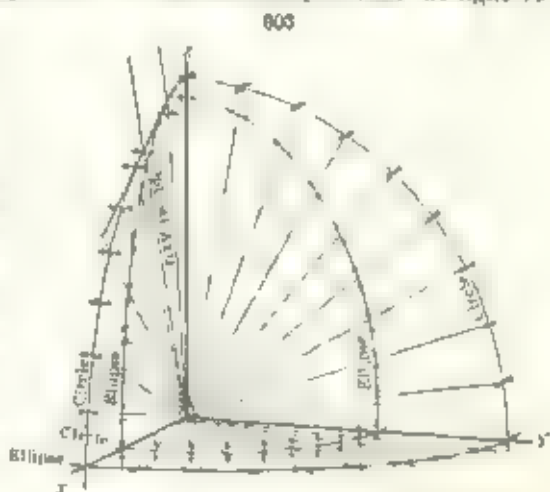


In the plane of the Y and Z directions, therefore, in a given moment of time, light will radiate from the center as ordinary and extraordinary rays the wave-fronts being represented by an ellipse within a circle.

The last and most important plane to be considered is that of the X and Z directions, Fig. 602. Light will radiate from the center toward X and Z and all intermediate directions with vibrations parallel to OY, hence traveling with a uniform and intermediate velocity, $1/\beta$. The distance traveled in a given moment of time is represented in Fig. 602 by the circle with the radius $1/\beta$. There will likewise travel in the direction OZ a ray resulting from vibrations parallel to OX, hence moving with the maximum velocity, $1/\alpha$.

Also a ray will travel in the direction OX with vibrations parallel to OZ, hence moving with the minimum velocity, $1/\gamma$. In intermediate positions the light velocity will be proportional

to the radii of an ellipse with $1/\alpha$ and $1/\gamma$ respectively as its semi-major and semi-minor diameters, Fig. 602. In the plane of the X and Z directions, therefore, in a given moment of time, light will radiate from the center as ordinary and extraordinary rays the wave-fronts being represented by a circle intersecting an ellipse. It is to be noted that in this last plane there are four points where the two wave-fronts coincide. In other words, light traveling along the radius lines connecting these points will be moving with uniform velocity and consequently along these directions there will be no double refraction. These directions are known as the optical axes of the crystal and since there are two of them the optical group is spoken



of as biaxial. The character of these optic axes will be more fully developed in a later article.

In the above paragraphs the wave-fronts for light passing in the three principal optical planes of the crystal have been discussed. Fig. 403 represents the wave-fronts in these three planes as they appear when bounding one another. The complete wave-surfaces for light propagated in all directions consist of warped figures which combine to be either circular or elliptical wave-fronts already described in the three principal planes and have intermediate positions elsewhere. The only satisfactory way to represent these complete surfaces is by means of a model.

405. The Fresnel Ellipsoid. The study of the behavior of light in biaxial crystals, especially from the mathematical point of view, has been greatly facilitated by the conception of two ellipsoids which are known as the Fresnel ellipsoid and the Fletcher indicatrix. The Fresnel ellipsoid, or vibration velocity ellipsoid, is an ellipsoidal solid, the three principal axes of which are made proportional to the velocities of light vibrating parallel to X , Y and Z respectively. From it can be derived the velocity and direction of vibration of any ray of light passing through the crystal in any direction. In general, a plane passed through the center of the ellipsoid will have an elliptical outline. The major and minor diameters of such an elliptical section will give the directions of vibration and their lengths will be proportional to the velocities of the two rays which can pass through the crystal in a direction normal to the chosen plane. Further, in such an ellipsoid there will be two sections that are circular in outline. Since all the radii of such sections are equal, light passing through the crystal in these directions normal to them must have constant velocity and cannot be doubly refracted or polarized. The circular sections of the Fresnel ellipsoid are therefore perpendicular to what are known as the secondary optic axes of the crystal (see further Art. 407).

406. Biaxial Indicatrix.* It is found further that the optical structure of a biaxial crystal can be represented by an ellipsoid, known as the indicatrix, having as its axes three lines which are at right angles to each other and proportional in length to the indices α , β , γ . This is analogous to the similar figure for uniaxial crystals described in Art. 390.

This ellipsoid, whose axes represent in magnitude the three principal refractive indices, α , β , γ (where $\alpha < \beta < \gamma$ (see Fig. 604), not only exhibits the character of the optical symmetry, but from it may be derived the velocity and plane of vibration of any light-ray traversing the crystal.

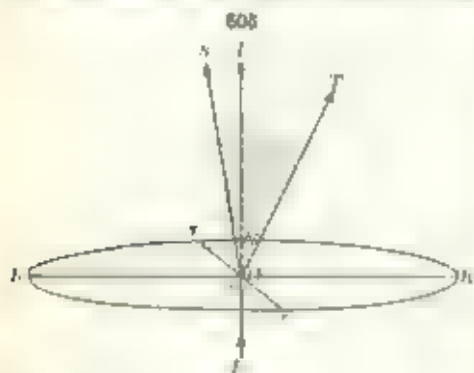
In general, any section through the indicatrix will be an elliptical section. The major and minor diameters of such a section will yield the directions and planes of vibration of the two possible rays whose wave-fronts have this plane or in other words whose wave-normals coincide with the line perpendicular to the section. If



Biaxial Indicatrix

* L. Fletcher. The Optical Indicatrix and the Transmission of Light in Crystals. London, 1892.

this section happens to be one of the three principal sections of the indicatrix (Fig. 604, AB , $A'A'$ or BC , BC'). Fig. 604, its major and minor diameters give the directions of vibration and their lengths the indices of refraction of the two rays. If the incident ray has some direction different from the direction of the three axes of the indicatrix, upon the derivation of the character of the two refracted rays is not as simple. Let Fig. 605 represent such an optical section normal to L , L' . In this case the major and minor diameters AB , AB' and BC , BC' of the elliptical section lie in the vibratory planes of the two rays but the direction of vibration of the latter will be somewhat different, to the elliptical section. These directions of vibration may be obtained by erecting normal to the surface of the indicatrix at the points k and r where the major and minor diameters of the elliptical section meet that surface. These normals RN and rn , when extended to the line L , L' , yield the directions of vibration and the refractive indices of the two refracted rays. Their directions of transmission (the lines OS and OT) will be perpendicular to these normals and since neither of the latter lies in the elliptical section, both rays will be refracted and behave as extraordinary rays.

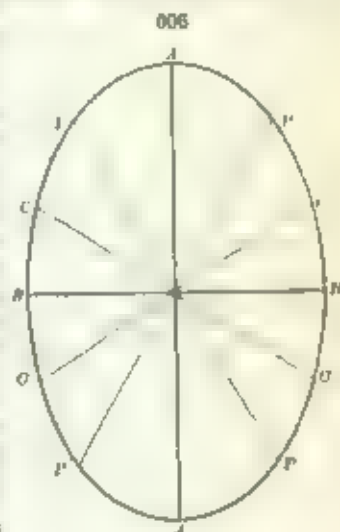


There are two special sections of the indicatrix that require notice. The line BOB (Fig. 604) is longer than the line AOA but shorter than the line COO . Obviously, somewhere between AOA and COO there will be a diameter of the ellipse AC , AC' which will be equal in length to BOB . There are two such lines as SOO and $S'O'S'$ in Fig. 604. The major and minor diameters of these sections of the indicatrix, $BSBS$ and $B'S'B'$, are equal and the sections therefore become circles. Consequently light passing through a section of a crystal cut parallel to either of these circular sections of its indicatrix will have a uniform velocity and may travel in any transverse direction. In other words, there will be no double refraction along the axis normal to these two sections. These axes constitute what are known as the primary optic axes of the crystal, see further in Art. 407.

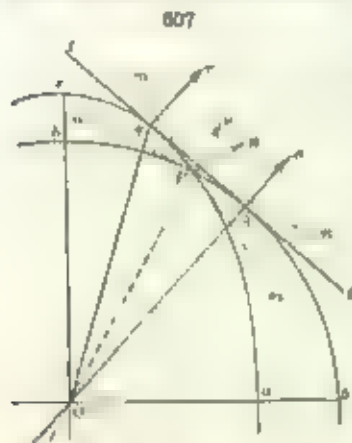
The major and minor diameters of any section of the indicatrix yield the traces upon that section of the planes of vibrations of the two rays whose wave normals are perpendicular to the section. In other words, the major and minor diameters of the elliptical section of the indicatrix give the directions of extinction of a crystal section having this optical orientation. Further, these extinction directions bisect the angles made by the traces upon the section of two planes, each of which includes the pole of the section and one of the two optic axes. This may be demonstrated by aid of Fig. 606 which represents a general elliptical section of an indicatrix. AA and BB are the major and minor diameters of the ellipse and so represent the extinction directions of the mineral section. CC and $C'C'$ represent the intersections of the two circular sections of the indicatrix with this elliptical section. As these lines are

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diameters of equal circles they must be equal in length and it therefore follows from the geometric nature of an ellipse that the angles AOB and AOB' are equal. Let the line $P'P$ represent the intersection with this elliptical section of a plane in which lies the normal to the section and one of the optic axes. Since this plane contains an optic axis it must be perpendicular to the circular section of the indicatrix of which the line $C'C''$ is a diameter. Also since this plane contains the normal to the elliptical section in question it must be at right angles to the latter plane. Under these conditions it is obvious that the lines $P'P$ and $C'C''$ in Fig. 603 must be at right angles to each other. In the same way it can be proved that the lines $P'P$ and $C'A$ are also at right angles to each other. Since the angles AOB and AOB' are equal and the angles $P'OB$ and $P'OB'$ are also equal it follows that the angles AOP and AOP' are likewise equal. In other words the lines $A'A$ and $B'B$ representing the directions of extinction of the section bisect the angles made by the traces upon the section of the two planes which respectively pass through each optic axis and the normal to the section. This fact will be made use of in Art. 417 in examining the characters of the biaxial interference figure.



407 Primary and Secondary Optic Axes.— It has already been stated (Art. 406) that there are two directions, namely, those normal to the circular cross-sections of the indicatrix ($SS, S'S'$, Fig. 604) which are of such a character that all light having its wave-normals parallel to them travels in the crystal with uniform velocity. These two directions bear so close an analogy to the optic axes of a uniaxial crystal that they are also called *optic axes*, and the crystals here considered are hence named *biaxial*. In Fig. 602, which represents a cross-section of the wave-surfaces in the plane of the X and Z directions, these optic axes have the directions $SS, S'S'$ normal to the tangent planes $tt, t't'$ and the direction of the external wave is given by the normal So (Fig. 607).



Properly speaking the directions mentioned are those of the *primary optic axes*, for there are also two other somewhat analogous directions, $P'P, P'P'$, of Fig. 602 called for the sake of distinction the *secondary optic axes*. The properties of the latter directions are obvious from the following considerations.

In the section of the wave-surface shown in Fig. 602 (also enlarged in Fig. 607), corresponding to the axial plane XZ , it is seen that the circle with radius

1 intersects the ellipse whose major and minor axes are $\frac{1}{\alpha}$ and $\frac{1}{\gamma}$ in the four points P, P', P'', P''' corresponding to those of rise and set of primary rays is obviously the same for both rays. Hence within the crystal these rays travel together without further separation. Since, however, there is a difference of speed for these two rays, for the angles for which a representation is made for the other two rays (Fig. 607) they do not follow the same path, emerging in fact as two separated waves, which we also may represent by the notation P'' and P''' . These two rays, $P''P'$, $P'''P'$ then interfere, and wherever in the pages following you find an asterisk (*) you will always be primary rays, but at those points the difference is $\frac{1}{\alpha}$ (Fig. 602) or $\frac{1}{\gamma}$ (Fig. 607). In practice, however, as remarked in the next article, no angular variation between the two sets of axes is usually very small, perhaps 1 or even.

404 Interior and Exterior Conical Refraction — The incident plane is the plane of the

$\frac{d}{dt} \left(\frac{\partial L}{\partial \dot{x}} \right) = \frac{\partial L}{\partial x}$

1. 凡在本行开立存款账户的客户，均可向本行申请开立定期存款账户。
 2. 定期存款账户的开立，须由客户填写《定期存款开户申请书》，并提供有效身份证件。
 3. 本行定期存款账户分为整存整付、零存整付、整存零付、零存零付四种类型。
 4. 定期存款账户的期限分为三个月、六个月、九个月、十二个月、十八个月、二十四个月、三十六个月、四十八个月、六十个月、七十二个月、八十四个月、九十六个月、一百零八个月、一百二十个月。
 5. 定期存款账户的利率按本行公布的利率表执行。
 6. 定期存款账户的利息按季结息，到期一次支取本金和利息。
 7. 定期存款账户的提前支取，须由客户填写《定期存款提前支取申请书》，并提供有效身份证件。
 8. 定期存款账户的提前支取，按本行公布的提前支取利率执行。
 9. 定期存款账户的销户，须由客户填写《定期存款销户申请书》，并提供有效身份证件。
 10. 定期存款账户的销户，按本行公布的销户利率执行。

[illegible]

* The axial angle may equal 90° when the inductance satisfies the following equation:

$$\frac{1}{1+\sqrt{2}} + \frac{1}{1+\sqrt{3}} = \frac{1}{1+\sqrt{5}} + \frac{1}{1+\sqrt{6}}$$

occurs it is true for light of a certain color* (wave-length) only and not for others.

The X and Z optical directions bisect the angles between the optic axes and are therefore known as *bisectrices*. The one that bisects the acute axial angle is called the *acute bisectrix* (or H_x), while the one bisecting the obtuse angle is the *obtuse bisectrix* (or H_z). If the word *bisectrix* is used alone without special qualification it is always to be understood as referring to the acute bisectrix.

Either X or Z may be the acute bisectrix. If X is the acute bisectrix the substance is said to be *optically negative*, while if Z is the acute bisectrix it is *optically positive*.

Roughly expressed, the optic axes will be nearer to Z than to X — that is, Z will be the bisectrix — when the value of the intermediate index, β , is nearer to that of α than to that of γ . It is obvious (cf. Fig. 602) that in this case, as the angle diminishes and becomes nearly equal to zero, the form of the spheroid then approaches that of the prolate spheroid of the positive uniaxial crystal as its limit (Fig. 583, p. 281), thus showing the appropriateness of the + sign here used.

On the other hand, the optic axes will be nearer to X than to Z — that is, X will be the bisectrix — if the value of the mean index β is nearer to that of γ than to that of α . Such a crystal, for which $H_x = X$, is called *optically negative*. In this case the angle the more the ellipsoid approaches the oblate spheroid of the negative uniaxial crystal (Fig. 582, p. 281).

The following are a few examples of positive and negative biaxial crystals:

Positive +	Negative
Sulphur	Aragonite
Enstatite,	Hypsthene
Topaz	Muscovite,
Barite,	Orthoclase
Chrysothite	Epidote
Albite	Axinite

410. Relation of the Axial Angle to the Refractive Indices. — If in a given case the values of α , β , and γ are known, the value of the interior optic axial angle known as $2V$ (see also Art. 418) can be calculated from them by the following formulas:

$$\cos^2 V = \frac{1}{\frac{\beta^2}{\alpha^2} - \frac{\gamma^2}{\beta^2}} \quad \text{or} \quad \tan^2 V = \frac{1}{\frac{\alpha^2}{\beta^2} - \frac{\beta^2}{\gamma^2}}$$

In the majority of cases, the difference between $\gamma - \beta$ and $\beta - \alpha$ is small, and then a close approximation to the value of $2V$ can be obtained from the

formula $\tan V = \sqrt{\frac{\alpha}{\gamma}}$. But in any case, the results of such calculations are usually not highly accurate, since a slight variation in the values of the indices of refraction will yield a disproportionate change in the value of the calculated angle.

* For danburite axial angle = $89^\circ 14'$ for green thallium, and $90^\circ 14'$ for blue (CaSO₄).

Examination of Biaxial Crystals in Polarized Light

411 Sections in Parallel Polarized Light with Crossed Nicol's.

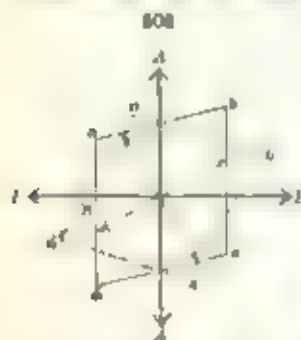
Interference Colors. Thin sections of biaxial crystals when examined between crossed nicols in general show some interference colors. This color will depend upon the following factors: the thickness of the section, the thickness of the section, the order of color, the birefringence of the substance, the light of the microscope, etc. The greater the difference between the x and y indices, the greater the order of color. The optical orientation of the section, in general, is nearer to section coming along parallel to the optical axial plane in which the vibration directions are the fastest and slowest rays, the higher will be the order of color and the order of the interference color.

Extinction Direction. A section when in general is crossed with slow during a complete revolution on the microscope stage four positions at 90° intervals in which it appears dark. These are the positions of extinction, or are those positions in which the vibration directions of the section coincide with those of the nicols. When the directions of extinction of a section are parallel or at right angles to a crystallographic axis or to the trace upon the section of a crystallographic axial plane, it is said to show *parallel extinction*. If the extinction directions are not parallel to these crystallographic directions the extinction is said to be *inclined*.

For example in Fig. 608, the two larger rectangular arrows represent the vibration directions of the two nicols and between which suppose a section of a biaxial crystal about to be placed so that one edge of a known crystallographic plane coincides with the direction of one of these lines. The vibration directions of the section are indicated by the dotted arrows and as in this position of the section these directions do not coincide with the vibration directions of the nicols the section will appear light. The section will

have to be turned to the position *a-b-c-d* in order to achieve this coincidence and so bring about extinction. The angle indicated in the figure) which it has been necessary to revolve the plate to obtain the effect described, is the angle which one of the vibration directions in the given plate makes with the given crystallographic edge and it is called the *extinction angle*. In some biaxial minerals the vibration directions for light of different colors may be sufficiently inclined to each other to permit complete extinction only when monochromatic light is used.

412 Measurement of the Extinction Angle. It frequently becomes important to measure as accurately as possible the extinction angle of a section. This is most commonly done with a microscope which is provided with a revolving stage having a graduated circle for measuring angles of rotation. In order to measure an extinction angle it is of course necessary to be able to locate in the section some definite crystallographic direction. This is usually provided by some crystal outline or surface crack. This crystallographic direction is brought parallel to one of the cross-hairs of the microscope and the angular position of the microscope stage noted. Then the stage is rotated until the section shows its maximum darkness. The angle between these two



from a left-handed and the other from a right-handed crystal. Above these are placed two wedges of quartz, a right-handed wedge above the left-handed plate etc. At the point where the wedge is zero in thickness to the plate beneath there will be zero rotation of the light and between crossed nicols this will produce a dark line across the field. As the distance increases from this point the amount of rotation of the light increases equally but in opposite directions on either side of the central line of the plate. Both halves of the plate will be equally illuminated if the central section is in the position of extinction, but if the latter is turned so that it adds or subtracts its birefringent effect to or from that of the quartz plate the two halves become differently illuminated. By moving the plate in or out a position can be found where this change of rotation is most marked. This quartz plate is used with a specimen of the mineral provided with a sand in such a position that the quartz plate may be introduced into the microscope fine at the lower plane of the ocular and with the central line of the specimen parallel to the plane of vibration of the polarizer. A cap is used above the ocular.

413. Determination of the Birefringence with the Microscope. The value of the maximum birefringence $\gamma - \alpha$ is obviously given at once when the refractive indices are known. It can be approximately estimated for a section of proper orientation and of measured thickness by noting the interference colors as described in Art. 363.

414. Determination of the Relative Refractive Power. The relative refractive power of the two vibration directions in a thin section is easily determined with the microscope in parallel polarized light by the method of compensation. This applies to any section whatever its orientation and whether uniaxial or biaxial. The methods employed have already been described in Art. 364.

A crystal section is said to have *positive elongation* if the direction of maximum optical anisotropy coincides with the direction Z of vibration. If with X the elongation is negative. The same terms are also used in general, according to the relative refractive power of the two directions.

415. Determination of the Indices of Refraction of a Biaxial Mineral. The *principal* refraction of a biaxial mineral are determined by the same methods as stated previously (see Art. 333), but a qualification is introduced being necessitated by the fact that three principal indices, α , β , and γ , are to be determined.

Measurement of the Angles of Refraction by Means of Prisms. Two or three prisms may be used to determine the three indices. If three prisms are used they are cut so that their edges are parallel respectively to the X , Y and Z directions of the crystal. In the case of a pleochroic mineral, in which these three directions are parallel to the three extinction directions upon the prism edges would have to be respectively parallel to the α , β and γ crystal axes. In crystals of the monoclinic and the triclinic systems the proper orientation of the three prisms is a matter of considerable difficulty. Each such prism will yield two refractions and polarized rays but only the one wave of light has to be examined parallel to the edge of the prism to be determined by the use of a Nicol. It is considered. In certain cases all three indices may be determined from two prisms. If no prism is cut so that not only is its edge parallel to one of the directions X , Y and Z but so that its mean plane contains not only one direction but one other then by the use of the method of minimum deviation an index may be determined from each of the two

refracted rays. Or with a small angle prism cut so that one of its faces contains two of these directions the corresponding two indices may be determined when the method of perpendicular incidence is used upon this face. In making these measurements it is important to note the crystallographic directions parallel to which the different rays vibrate. In that way the optical orientation in respect to the crystallographic directions can be determined.

Method of Total Reflection.—The method of total reflection for determining the indices of refraction of a biaxial mineral has the obvious advantage that only polished planes of the mineral are required instead of carefully orientated prisms. In general the same surface treatments will give with the total refractometer two better pictures of total reflection. Both of them should be made when the section is rotated. Four readings should be taken, corresponding to the maximum and minimum positions of each boundary. The largest and smallest angles will give the values for the axes for the greatest and least indices of refraction, n_x and n_z . The fourth axis of refraction can be determined from one of the other two measurements. There are several more or less convenient methods by which these values may be obtained. Readings can be taken in order to give what is the correct one for the index n_y . It is even more simpler but also used rather rarely having a polished crystallographic axis as a face. It will be found that in the second picture the two corresponding angles correspond to with one directly to rays in the first picture while the second angle shows no such correspondence. The angle that is common to the two pictures is the one desired. If the plate is cut so that the plane contains two of the axes of refraction X , Y , and Z , all three indices can be obtained easily from the angles μ . In this case one of the boundaries of total reflection is stationary for different positions of the plate. This corresponds to the ray whose vibration is normal to the surface of the plate. The other boundaries will vary its position as the plate is rotated and will not be stationary in its own position. The angles corresponding to the other two axes of refraction.

416. By Immersion in Liquids of Known Refractive Index.—The methods employed are similar to those described in Art. 330. In the use of axial immersion however, it is important to proceed with extreme care with view on direction the index determined in liquid. If the mineral is made up of irregular grains so that it is not other crystals studied previously, special attention should be given and the highest and lowest index values determined on a series of observations so that the case is appropriate to the system for study. Further if it is possible to obtain a series of grains see Art. 417 from the axial liquid grains those giving different angles will give the index n_y from the vibratory direction normal to the trace of the axes xy and either x or y . The index n_z will be given by any grain which is perpendicular to the axial plane, whether its reference figure is centered or not. Such a grain can be recognized by the fact that in a centered figure it is lying along the points of elongation of the optical axes, whether they are within or outside the field. In all cases pass through the center of the field. In case the mineral being studied has one or more good cleavages, the refracting grains will in general lie on the cleavage planes. It is at this the number of cleavages available for study but even if we have a good cleavage plane will often be parallel to one of the principal axes of the optical structure and therefore give definitely the values of one of the indices desired.

417. Sections of Biaxial Crystals in Convergent Polarized Light. — In general sections of biaxial crystals when examined in convergent polarized light show interference figures. The best and most symmetrical figures are to be observed when the section has been cut perpendicular to a bisectrix and preferably to the acute bisectrix. If such a section is examined under the conditions described in the case of uniaxial crystals (see Art. 397), figures similar to those shown in Fig. 610 will be observed. When the axial plane, i. e., the plane containing the two optic axes, lies parallel to the direction of vibration of the polarizer the figure is similar to that of Fig. 610 A. When these two directions are inclined at a 45° angle the figure is like that shown in Fig. 610 B.

Let us consider the interference figure in the parallel position, Fig. 610 A, and when viewed in monochromatic light. It consists of two dark bars that

610



Biaxial Interference Figures

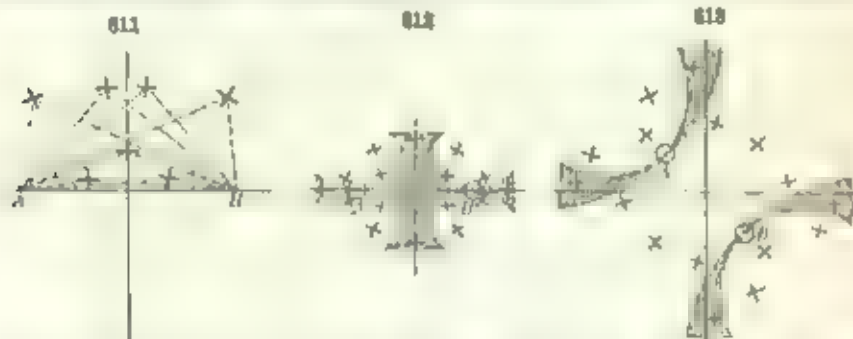
form a cross somewhat similar to the cross of a uniaxial figure. The horizontal bar is darker and better defined than the vertical one. About two spots on the horizontal bar, there will be observed a symmetric series of dark elliptical curves which, as they enlarge, coalesce, forming first a figure eight and then a double curve. As the section is rotated on the microscope or projection stage, the black bars forming the cross separate from the center and curve around the pole pivoting on these points until the 45° position, Fig. 610 B, has been reached, when that of a hyperbola.

A biaxial mineral has two directions, the directions of the optic axes, along which light travels with essentially no double refraction. At those points there would be no birefringence and consequently dark spots would result. As the points of the light rays become inclined to the directions of the optic axes the light suffers double refraction and in increasing degree as the amount of inclination becomes greater. Consequently at short distances away from these points the light must be refracted into two rays which have a difference of phase of one wave-length for a certain colored light, the yellow of the sodium flame in this case. The result will be extinguishment at such points. The assemblage of all points where the difference of phase of light is one wave-length is the first dark elliptical curve, called a *lemniscate*, shown in the figure. Further out will be found curves embracing the points where the difference of phase is two wave-lengths, three wave-lengths, etc.

If the interference figure is viewed in daylight instead of the monochro-

matic light the black curves will be replaced by colored ones. Each colored curve is produced by the elimination from the white light of some particular wave-length of light on account of the interference explained above.

The convergent bundle of light rays that pass through the section will each have its own particular plane of vibration. The directions of the planes of vibration for light emerging from the section at any given point can be approximately found, as explained in Art. 406, by bisecting the angles made by two lines connecting this point with the two points of emergence of the optic axes. Fig. 611 shows how the direction of vibration of the two rays emerging from given points can be obtained in this way. These directions of vibration vary over the field and consequently some of them must always be parallel or very nearly so to the planes of vibration of the Nicol prisms. When this happens the light is extinguished and darkness results. This explains



the formation of the black bars of the interference figure. Fig. 612 shows the bars in the crossed position and Fig. 613 when separated into the hyperbolic arms. As the section is turned the vibration directions of new points successively become parallel to the planes of the nicols and so the dark bars sweep and curve across the field.

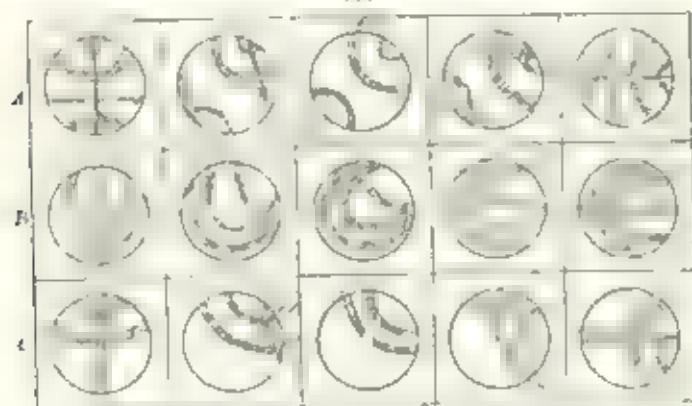
With a thick section or one of a mineral of high birefringence, the number of colored curves (when the figure is viewed in daylight) is greater than with a thinner section or one with low birefringence. An instructive experiment can be made by noting the changes in the interference figure obtained from a section of muscovite as the mineral is cleaved into thinner and thinner sheets. In most rock sections the minerals are ground so thin that their interference figures do not show any colored curves but rather only the dark hyperbolic bars.

The biaxial interference figure varies in appearance with the change in the angle between the optic axes. Where this angle is very small the figure becomes practically the same as that of a uniaxial crystal. Where this angle becomes greater than 60° the points of the emergence of the optic axes will commonly lie outside the microscope field. In the latter case the hyperbolic arms will appear as the section is brought into the parallel position, form a cross, and then as the section is further revolved will curve out of the field again. The larger the axial angle the more rapidly will the bars disappear from the field.

A symmetrical interference figure may also be obtained from a section cut perpendicular to the obtuse bisectrix. In general, the obtuse axial angle is

considerably larger than the acute angle and the interference figure will differ therefore in this respect from that obtained from the section cut perpendicular to the acute bisectrix. If, however, the axial angle approaches 90° , the distinction between the acute and obtuse interference figures is difficult to make. If the center of the figure coincides closely with the center of the field, it is possible sometimes to use the angle of rotation at which the hyperbolas leave the field as an indication as to whether the section is normal to the acute or obtuse bisectrix. In case it is normal to the acute bisectrix, the angle of rotation necessary to take the hyperbolas out of the field is greater than in the case of the obtuse bisectrix. It is reasonably certain that, if this angle is c , the angle between the position where the hyperbolas form a cross and the position where they disappear from the field is greater than 30° , the section is normal to the acute bisectrix. If the angle is less than 15° , it is normal to

614



Eccentric Axial Interference Figures

the obtuse bisectrix. For intermediate angles, unless the two sections of the same mineral are available for comparison, no positive decision can be made.

It is important to be able to recognize the biaxial interference figures which are obtained from various sections. They are chiefly characterized by the fact that the hyperbolic bars curve as they cross the field. In the case where the section is normal to a plane of symmetry of the optical structure the bar will cross the center of the field in a straight line parallel to one or the other cross-bar. In all other sections the bars are always curves. This characteristic distinguishes the figure from an eccentric uniaxial figure in which the bars of the crosses make no straight lines as the section is turned. Fig. 614 shows in the row A a series illustrating the appearance in different positions of the figure when the section is slightly inclined to the bisectrix, in row B a series where the section is cut perpendicular to an optic axis and the hyperbolic bar revolves in the field as upon a pivot. In this case the bar curves with its convex side toward the acute bisectrix. If the axial angle was 90° there would be no distinction between acute and obtuse bisectrices and the bar would then revolve as a straight line. Therefore such a figure indicates by the amount of the curvature of the bar the size of the axial angle. The figures given by planes cut nearly normal to an optic axis are often of great

use in the optical examination of a mineral. Sections which will furnish them are easily found by making those sections of the mineral that remain dark or nearly so during their rotation between crossed lenses. If the angle of rotation is only a figure of 180° the curved surface of the section that the section is cut on is not very much inclined to the plane of the section and consequently it is easier, whether A or Z, can be later found by noting the character of that extinction, whether it is a positive or negative figure. (See Art. 422). From this observation the positive or negative character of the mineral can be determined. In Fig. 414, is shown a series of figures where the section has a still greater inclination. A section cut parallel to the axial plane does not give a positive interference figure. Often it is so difficult to distinguish from the figure obtained from a section cut parallel to the optic axis of a mineral in this case. (See Art. 400). This series of figures increases as the axial angle of the lens is increased. When such an interference figure is viewed through a field and the following hypothesis proposed by the author and found to be true. In the parallel plane of the rays, rays are very weakly in the field. When turned from this position the light is broken and exceptional interference phenomena. One part of arms will appear to appear to quickly to be seen, but a careful observer may establish that when the light is parallel to the optic axis, the rays will appear to be in the same plane. If the light is turned away from the optic axis, the rays will appear to be in the same plane. Also, if the figure is viewed through a field, the figure will be the same as the figure obtained from a section cut parallel to the optic axis. (See Art. 400).

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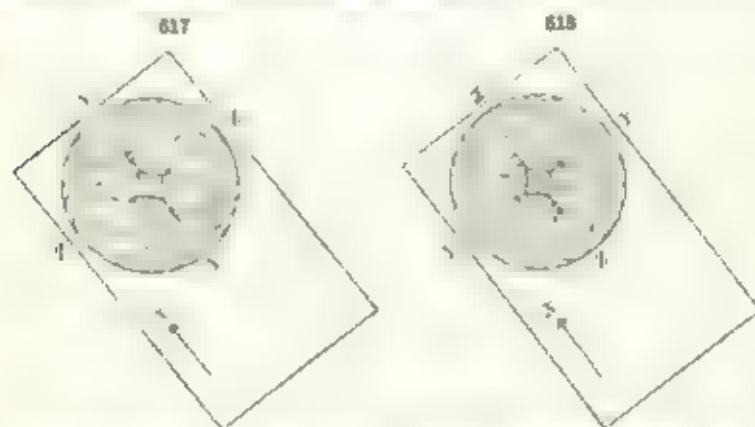
In the majority of cases, it is only the acute and not the chronic symptoms

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421 Determination of the Optical Character of a Biazial Mineral from Its Interference Figure Use of the Quartz Wedge If the position of the interference figure is such that the Δ position is at the center of the wedge, essential changes in the pattern through the Δ position are observed as the value of birefringence of the section is changed. In particular, if a crystal with a high birefringence is thin enough that the interference figure will be observable in the vibration direction of the quartz wedge, the interference figure will show the effect of the birefringence of the quartz wedge with a characteristic pattern of interference fringes. Now the interference figure is at the center of the Δ position and the character of the figure at Δ will vary with the position of Δ with the crystal in hand. The following table gives the character of the interference figure with a thickness of Δ in degrees, but the character of the interference figure will be the same for values of Δ in degrees and for the same thickness of Δ in degrees. The following table is for Δ in degrees, but the character of the interference figure will be the same for values of Δ in degrees and for the same thickness of Δ in degrees.

Am. J., 24, 347, 1901.
J. Schuchert, Manual of Petrographic Methods p. 835. Last is referred to the author's paper.
Winchell, Elements of Optical Mineralogy p. 260, 1928.

by the arrows shown in Fig. 617. On the other hand if the quartz wedge is so placed that its optical orientation is opposed to that of the section, the effect will be the same as if the section was being gradually thinned. The colored rings about the points of the optic axes will expand and they meet in the center as a figure eight and then grow outwards as a continuous curve. The directions of their movements are shown by the arrows in Fig. 618. Therefore, by knowing the optical orientation of the quartz wedge and noting the effect of its introduction over a section upon the interference figure, it is possible to determine the relative character of the two important extinction directions of the sections, that is, to determine whether the ray vibrating in



Determination of Optical Character of Mineral Minerals with Quartz Wedge

the plane which includes the optic axes is faster or slower than the one which vibrates in the plane at right angles to this line, on.

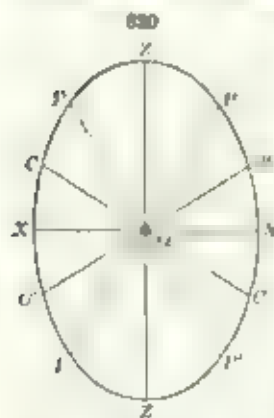
In the case of a positive uniaxial or acute biaxial, which in a symmetrical interference figure is the acute bisectrix normal to the section is the direction Z , consequently the direction of the line in the section which passes through the points of emergence of the two optic axes is the direction of the acute bisectrix and therefore the direction X . The direction Y then will lie in the plane of the section and at right angles to the line joining the points of emergence of the optic axes. In the case therefore of a positive mineral, the fast or ray has its vibration lying in the optical axial plane. With a negative mineral the direction X is away from the acute bisectrix and will be normal to the section, while the line Z will lie in the section along the line connecting the points of emergence of the optic axes. With a negative mineral, therefore, the vibration direction which lies in the optical axial plane is of the slower ray. By fitting together, the relative character of these two vibrations, first to the optical character of the mineral is determined. The effects practically as they appear in figure which is perpendicular to a thin section with a quartz wedge approach to those described above. It is important, therefore, that the positions of the two bisectrices be definitely known. With sections that are very thin or with minerals of low birefringence the interference figure may show only the black hyperbolas without any colored rings. In such cases frequently the introduction of the quartz

wedge in such a position that its optical orientation is parallel to that of the section will suffice to so thicken the section in effect as to cause the appearance of colored rings. Further, with such sections it is possible to establish the directions in the section that are parallel, and at right angles to the trace upon the section of the optical axial plane. Then by use of the sensitive tint, when the convergent lens has been removed the character of the vibrations parallel to these two directions is easily determined.

422. Determination of the Optical Character of a Biaxial Mineral from the Interference Figure Obtained from a Section Normal to an Optic Axis.—The optical character may also be determined from the interference figure obtained from a section normal to an optic axis. As stated in Art. 417, such a figure consists of a single bar more or less curved, and rotates as on a pivot in the center of the field when the section is turned.

The curve of the bar is always convex toward the acute bisectrix and concave toward the obtuse bisectrix. If the axial angle is 90° or nearly so, the bar becomes straight. In such a case the determination of the positive or negative character of the mineral is impossible, but fortunately such cases are rare. In this interference figure (fig. 619) the trace of the axial plane acts as a curve of the bar and the optical direction is tangent to it. Light emerging at points beyond the center of the field in the direction of the acute bisectrix (i.e., on the convex side of the curve) would have one of its vibrations parallel to $\{$ and the other inclined toward the direction of the obtuse bisectrix. On the other side of the bar in the direction of the obtuse bisectrix light would have one of its vibrations still parallel to $\{$ and the other inclined toward the acute bisectrix. These facts may be more clearly understood by a consideration of fig. 620. It represents the principal elliptical section of the indicatrix of a biaxial mineral parallel to the optical axial plane. The section under consideration is normal to an optic axis, as $P-P'$, and is represented in the figure by the line $C-C'$ which lies in the circular section of the ellipsoid. The direction $\{$ is normal to the plane of the figure at its center O , and is always one of the parameters of any elliptical section of the indicatrix that is normal to the axial plane. Light is passing through this section as a cone of rays with varying inclinations. Therefore for light passing in directions that lie between the lines

619



$P-P'$ and $Z-Z'$, the variable semi-diameter of the elliptical sections of the indicatrix that are normal to these axes will gradually decrease from the angle of $O-C'$ (which is equal to $\frac{1}{2}$) to that of $O-A'$, that is, in all cases it will be less than $\frac{1}{2}$. All such sections therefore will have the ray which vibrates in the axial plane partake more of the nature of the vibrations parallel to the obtuse bisectrix. In the same way, the elliptical sections normal to the

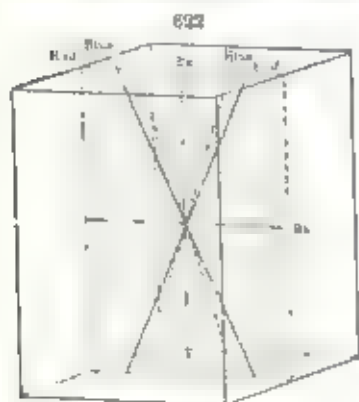
convergent light both will show biaxial interference figures with the points of emergence of the optic axes lying as illustrated in *B* and *C* (Fig. 621). The axial angle observed with a section parallel to (001) is much smaller than that obtained from (010). Consequently the acute bisectrix is normal to the



Optical Orientation of Aragonite

Figure 621, and since it is the direction X the mineral is optically negative. These facts of optical orientation may be summarized in the following, optically = X is parallel to (100), Y is parallel to (001).

426 Dispersion of the Optic Axes in Orthorhombic Crystals. In determining the values of refraction of crystals, a means of dispersion method it is found that when a monochromatic ray of white light is refracted ray will disperse it into the white light disperses into a primary color. The



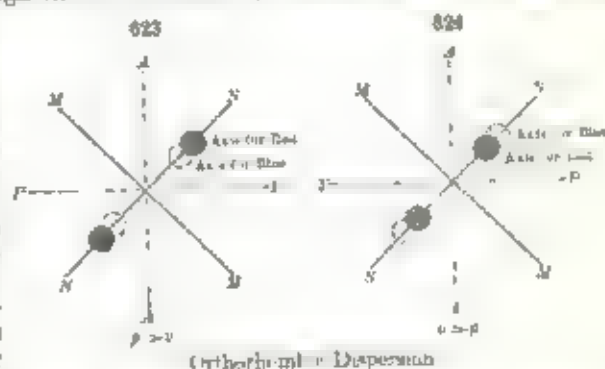
Dispersion of the Optic Axes

action of the dispersion is usually small but in certain cases it becomes considerable. Obviously since the angle of refraction varies in this way with the different wavelengths of light the indices of refraction will vary. In axial minerals as already stated the optic axes are directly connected upon the relative values of the three values of refraction, x , y , and z . As these values may show tendency of dispersion, light upon the wave-length of a refracted ray, it follows that the optic axes will also vary with the color of the light used. In Figure 622 represents a case in which the angle between the optic axes of red light is greater than that for blue. The opposite condition may hold,

in which the angle for blue is greater than for red. Then the optical figures for the colors are different. The light will not exactly coincide with that produced by red light. The differences of both figures

will be the same but the position of the points where the optic axes emerge will be different and consequently the positions of the hyperbolas and lemniscate curves will also be different. In the case of orthorhombic crystals the dispersion will always be symmetrical to the two symmetry planes of the indicatrix that pass through the acute bisectrix, i.e., the directions $M-M'$ and $N-N'$ in Figs. 623 and 624. This particular

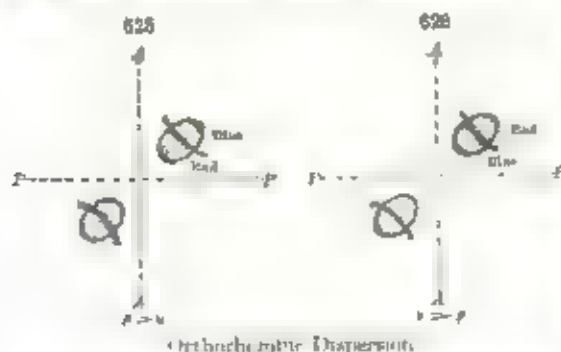
type of dispersion is said to be *orthorhombic dispersion*. In order to distinguish it from that observed in biaxial crystals of other systems. The two possible cases of orthorhombic dispersion are shown in Figs. 623 and 624. In expressing these two cases the Greek letters ρ (for red) and σ (for violet)



are used. When the axes for red light are more dispersed than those for blue that fact is expressed as $\rho > \sigma$ or in the reverse case it is $\rho < \sigma$.

In the majority of cases the effect produced upon the interference figure by the dispersion of the optic axes is too slight to be noted. In exceptional cases where the amount of dispersion is large the effects are clearly seen. The hyperbolic lines which are ordinarily black throughout, will when the figure is observed in white light be seen, near the center to be bordered on one side by a red fringe and on the other by a blue one. The first one or two of the colored lemniscates will also be bordered out along the line joining the two optic axes. As already stated these changes in the appearance of the figure

will always be symmetrical in respect to the traces of the two symmetry planes lying at right angles to each other. In the case, Fig. 623, where the axes for red light are farther apart than those for blue ($\rho > \sigma$), the hyperbolas in the interference figure for the two different wavelengths of light will not contact and the ones where the red light is concerned will be farther out than



those for blue light. When red light is brought out of the white light blue remains, and conversely when blue is subtracted the resultant color is red. Consequently in this case the hyperbolic ones will be bordered on their concave sides by blue and on their convex sides by red, Fig. 625. In the other case, where $\rho < \sigma$, the hyperbolas will be bordered on their concave sides by red and on their convex sides by blue, Fig. 626. In other words, if blue

light shows at the larger angle α means that red light has been eliminated from these positions and the optic axes for red are more dispersed than those for blue, etc.

Special Optical Characters of Monoclinic Crystals

427. Optical Orientation of Monoclinic Crystals. In monoclinic crystals there is one axis of symmetry, the b axis, the plane of axes, and the plane of symmetry. The plane of axes and crystallographic axes. There are only two crystallographic axes that are at right angles to each other. One of the three chief principal directions, X , Y , or Z , coincides with the b crystallographic axis, while the other two lie in the symmetry plane (Fig. 627) and not parallel to the crystallographic axes. There are, however, three possible cases.



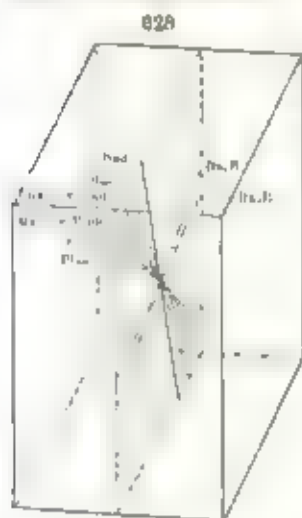
Optical Orientation of Crystals

If Y coincides with the axis b and X is parallel to the a axis, then the Z axis is parallel to the c axis. In this case the Y and Z axes lie in the crystallographic plane, which therefore becomes the optic axis plane. If X or Z coincides with the b axis the optic axis plane will be a right angle to the b axis. In the latter case the Y axis will be parallel to the b axis. In a crystal of a mineral crystal, it is usually the best plan to which the crystal is oriented. Fig. 627 represents such a crystal, obtained from an ordinary crystal of gypsum. The cleavage planes are 100 and 010 will serve to give the crystallographic orientation. By rotation of the crystal in a convergent light, it is possible to determine the position of the optic axis plane. When the crystal is rotated so that the Y axis is parallel to the direction of the crystallographic axis b , the angle of extinction is 90° . The optical character of the crystal can be easily determined by the use of convergent light. When the Y or Z axis is parallel to the b axis, the X axis is parallel to the a axis. In this case the Y and Z axes lie in the crystallographic plane, which therefore becomes the optic axis plane. When the Y or Z axis is parallel to the b axis, the X axis is parallel to the a axis. In this case the Y and Z axes lie in the crystallographic plane, which therefore becomes the optic axis plane. When the Y or Z axis is parallel to the b axis, the X axis is parallel to the a axis. In this case the Y and Z axes lie in the crystallographic plane, which therefore becomes the optic axis plane.

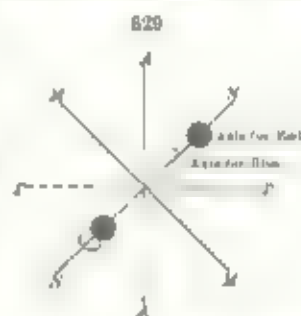
428. Extinction in Monoclinic Crystals. Since only one of the three principal optical directions, X , Y , or Z , of a monoclinic crystal coincides with

crystallographic axis, namely the symmetry axis b , it follows that only sections in the optical zone, which are parallel to this axis, i.e., sections in the optical zone, will show parallel extinction. All other sections will exhibit inclined extinction.

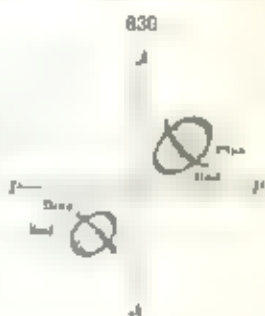
429 Dispersion in Monoclinic Crystals. As previously stated there are three possible optical orientations of a monoclinic crystal. In the first case, namely that discussed by *concordia* with b as the symmetry axis, and the optic axial plane coincides with the symmetry plane ($\sigma = 90^\circ$). In the two other cases either the vibration direction X or Z



Inclined Dispersion



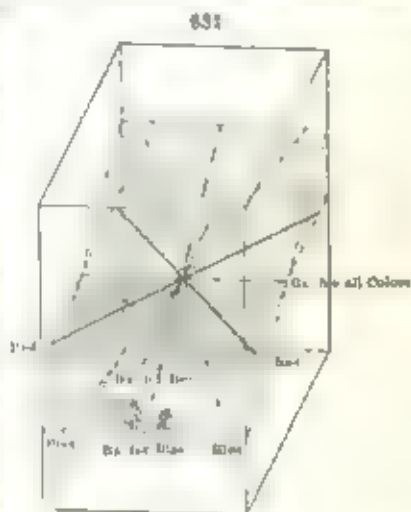
Inclined Dispersion $\sigma >$



coincides with the crystallographic axis b and the optic axial plane is at right angles to the crystallographic symmetry plane. Under these conditions either

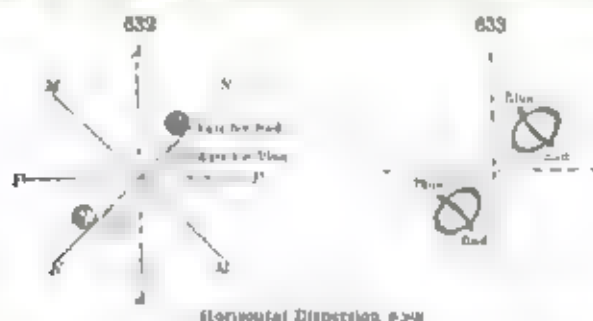
of the three possible optical orientations will coincide with the axis b . Each of these three positions may produce a different kind of dispersion. It should be emphasized that the phenomenon of dispersion is said to be clearly observed only when it is only in unusually thick sections, necessary.

431 Inclined Dispersion. In this dispersion is observed when the vibration direction X coincides with the axis b . This is illustrated in Fig. 428. In this case in every way the axial angle varies for light of different wavelengths and at the same time of these angles $2V$ is always different. So, here, both the optic axes and the bisectrices may be inclined. In Fig. 428 where $\sigma > 90^\circ$ the angle between the optic axes for red light is greater than that for blue. But because of the dispersion of the bisectrices it follows that on one side the point of emergence of the optic axes for red light lies beyond that for blue, while on the other side the conditions are reversed. Also the optic axes for red



Horizontal Dispersion

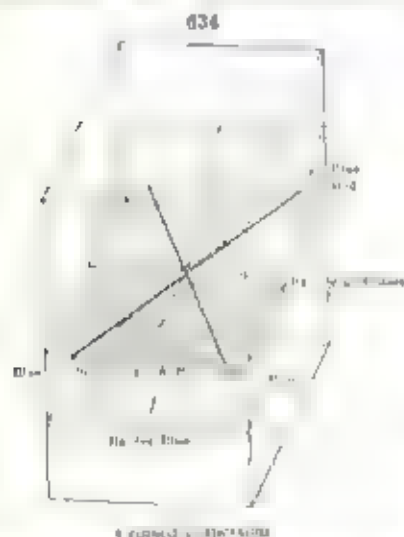
and blue will be further apart on one side of the interference figure than on the other side. With this sort of dispersion the interference figure will be asymmetrical only in respect to the line which is the trace upon the section



Horizontal Dispersion, $\rho > v$

of the optical section, $N-N$ (Fig. 629) but is asymmetrical to the line at right angles to it, $M-M$.

Inequal dispersion is shown in the interference figure by the fact that the extreme isopters to ρ and v are not reverses in the two cases. If $\rho > v$ then the line $N-N$ of the red will be wider than the line $M-M$ of the blue. Further, the amount of dispersion shown is much greater with one half than with the other. Fig. 632 represents a case of $\rho > v$ and dispersion.



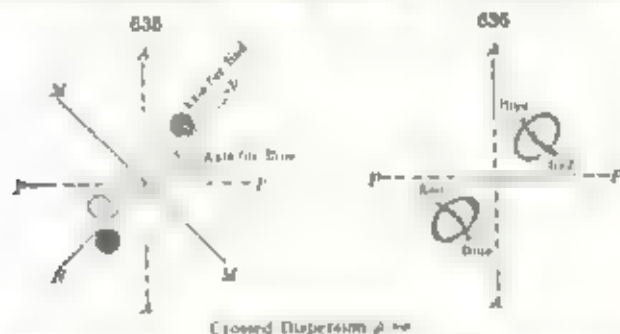
Case 2. Horizontal Dispersion. —

In this case the crystallographic axis b coincides with the obtuse bisectrix which may be either the X or Z direction depending on whether the crystal is optically positive or negative in character. In this case the direction of the acute bisectrix is fixed for light of all wave-lengths. The angle between the optical axes may vary and for a given direction of the crystallographic axis b the acute bisectrix may vary so long as it lies in the crystallographic ac bisectrix plane. In a few words the ac planes may be dispersive (see Fig. 632). The points of intersection of the optical axes, when $\rho > v$, for blue and red light, must therefore be as that shown in Fig. 632. It will be noted that in this case the interference figure is not of center from which the acute bisectrix is perpendicular to the obtuse bisectrix, as

is true when the line $M-M$ but in a section in a direction $N-N$. Fig. 634 shows the effect of horizontal dispersion upon the interference figure.

Case 3. Oblique Dispersion. — In this case the crystallographic axis b coincides with the acute bisectrix which may be either the X or Z direction

depending upon the optical character of the crystal. In this case the direction of the optic-bisectrix shown for light of all wave-lengths. The angle between Y and Z may vary and further the position of the axial planes for different wave-lengths may vary as long as they remain perpendicular to the crystallographic planes. A case of this sort is shown in Fig. 634. The points of emergence of the optic axes when $Y > Z$ for blue light and $Z > Y$ for red light might here be like the show in Fig. 635. It will be seen that in this case the figure is symmetrical to the line MM' and Y is not only to the central



point of emergence, i.e., the point of emergence of the optic-bisectrix. Fig. 636 shows the effect of crossed dispersion upon the interference figure.

Special Optical Characters of Triclinic Crystals

430. Optical Orientation of Triclinic Crystals. The center of the optical figure coincides with the center of the crystal, and the optical axes are so farther in respect to the crystallographic directions.

431. Extinction in Triclinic Crystals. Since there is no plane of symmetry, the optical axes will show a characteristic extinction.

432. Dispersion in Triclinic Crystals. Because of the lack of compensation between the optical axes, the optical figure will show a characteristic dispersion. The optical axes will show a characteristic dispersion. The optical axes will show a characteristic dispersion.

433. Suggestions as to Methods and Order of Optical Tests upon an Unknown Mineral. *Preparation of Material.* The size and character of the fragments are of great importance. The fragments should be small enough to be held in the fingers. The fragments should be small enough to be held in the fingers. The fragments should be small enough to be held in the fingers. The fragments should be small enough to be held in the fingers.

glass. In the majority of cases it will prove more expeditious and convenient to place the fragments in an oil.

Order of optical tests—Below is given a brief outline of the natural order of observations and tests to be made upon the minerals.

1. *Observe mineral in plane polarized light without the upper nicol*
 - a. Note color of mineral whether uniform or not.
 - b. By turning slide in microscope stage test for possible pleochroism. If in two or three exhibits pleochroism it cannot be isotropic. (Certain minerals possible to exhibit axis of absorption with crystallographic directions.)
 - c. Note crystals on lines of any cleavage cracks, etc.
 - d. Note any reflections their shape and arrangement.
 - e. Index of refraction. Determine approximately the refractive index. Note character of relief and determine whether mineral has a higher or lower index than the medium in which it is immersed (see Art. 830).
2. *Observe mineral in plane polarized light with crossed nicols*
 - a. If the section is dark between crossed nicols and remains so during the rotation of the stage the mineral is either isotropic or anisotropic in perpendicular to its optical axis. In the latter case test as indicated below under 3a.
 - b. If the section is alternately light and dark during the rotation of the stage the mineral is anisotropic.
 - c. Note position of extinction or directions. If they are inclined to some extent with crystallographic directions measure the angle of inclination.
 - d. Determine the relative character of the two vibration directions of the section. There are two extinction directions, as to which corresponds to the faster and which to the slower ray. Test to be made with quartz wedge or sensitive tint (see Art. 354).
 - e. Find a grain showing the highest order of interference color and so approximately determine the strength of the mineral's birefringence.
 - f. By comparing with oils of known refractive indices determine as accurately as possible the range of refractive indices shown by the mineral. It may be possible to supplement with tests made under 3 and determine the values for certain of the principal refractive indices.
3. *Observe mineral in convergent polarized light with crossed nicols*
 - a. Note whether the mineral shows an interference figure and if so whether it is axial or off-axial.
 - b. If centered as in axial figure at the point on the optic axis in position of the point of the given section and it possible determine the positive or negative character of the mineral.
 - c. If the mineral is biaxial determine the position of the axial plane in respect to the section. Determine if possible the positive or negative character of the mineral. Obtain if possible an approximate value as to the size of the axial angle. Note any evidences of lamination.

Note — In making the above tests it is helpful to keep, as far as possible, a good record of the results, something like that illustrated in Fig. 621.

434. **Effect of Heat upon Optical Characters.**—The general effects of heat upon crystals as regards expansion etc. are spoken of later. It is convenient, however, to consider here briefly, the changes produced by this factor in the special optical characters. It is assumed that no alteration in the chemical composition takes place and no abnormal change in molecular structure. In general, the effect of a temperature change causes a change in the refractive indices. In the majority of cases the indices decrease in size with rise of temperature but in certain cases the reverse is true. It is consequently important in any exact statement of a refractive index to give the temperature at which it was determined. The particular facts for the various optical classes are as follows:

1. *T* drop crystals remain isotropic at all temperatures. Crystals, however, which have sodium chlorate (NaClO₃) of class 5 p. 88 show enantiotropy and may have their rotatory power altered, in this substance it is increased by rise of temperature.

2. *Gamma crystals* similarly remain asexual with rise or fall of temperature: the only change noted is a variation in the relative values of ω and ϵ that is, the strength of the double refraction. This increases, for example, with quartz and grows weaker with beryl and quartz. It is, further, interesting to note that the refractive power of quartz increases with rise of temperature, but the relative refractive indices of the spectrum rays are seen by the same

5. With λ_{eff} as a guide, the effect of change of temperature varies with the system to which they belong.

[illegible]

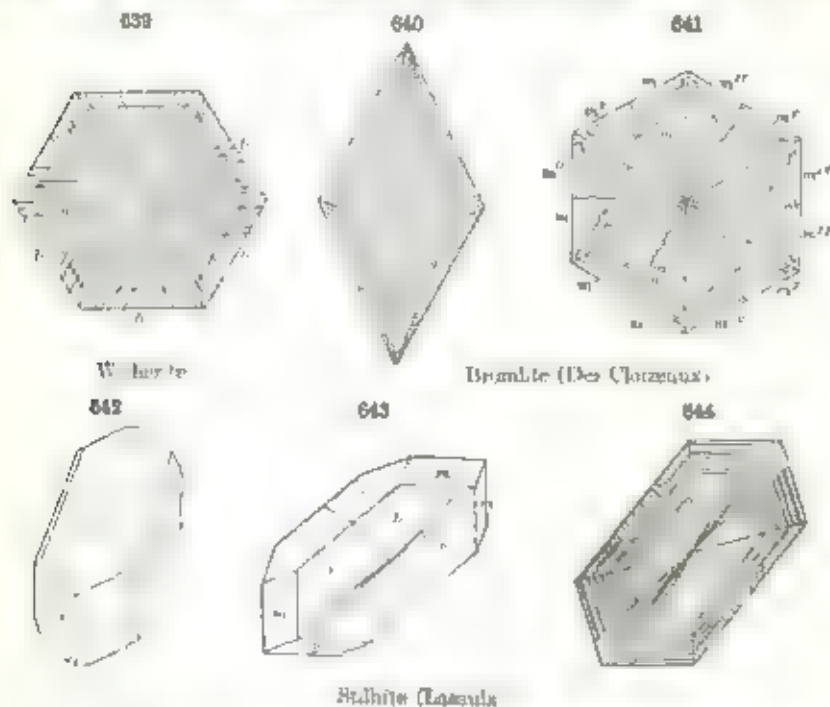
In the case of orthorhombic crystals the position of the three rectangular axes can change after anneal since they must not coincide with the crystallographic axes. The values of the energy w and μ , however, may change and hence with them also the optic axial angle $2V$ and a change of axial plane or 10° ρ and character of the isochrode.

With *monoclinic* crystals, one *optic axis* must coincide at all temperatures with the *axis of symmetry*, but the position of the other two in the plane of symmetry may alter, and the with the possible change in the value of the *refractive indices*, may cause a variation in *birefringence* (or kind of dispersion) as well as in the *axial angle*.

With *triclinic* crystals, with the positions of the other axes and the values of the refractive indices may change. The observed optical characters may therefore vary widely.

[illegible]

641. Fig. 642 shows a simple crystal of stibite. Fig. 643 is the common type of twin crystal and Fig. 644 illustrates how the crystals are twinned. It is revealed in polarizing light under a microscope in grain 641 that it will be understood that the axial cleavage planes of two crystals where the parts are superposed (etch show many peculiarities) of stibite crystals (Fig. 645) will serve as an illustration.



Wulffite

Bismite (Des Cloizeaux)

Stibite (Lamotte)

438. A particularly interesting case, related to the subject discussed in the preceding article, is that of the special properties of a superposed cleavage-superposed twin. If there are two crystals, one of rectangular form, be superposed and so placed that the axes of the crystals are at equal angles of 45° or 135° with each other, the effect is that polarized light which has passed through the crystal suffers a circular polarization, with a rotation (right or left) according to the way in which the sections are built up. The interference figure resembles that of a section of quartz cut normal to the axis.

If the sections are thin and very thin, the combination of the phenomena of birefringence and circular polarization is very much higher, upon the separate phenomena structure in a crystallized medium showing circular polarization. Further that may mean that in an external world it is possible to have in sections of certain crystals (e.g. of stibite or perovskite) which are biaxial and others that are uniaxial, the latter being due to an intimate twinning after the method of biaxial portions.

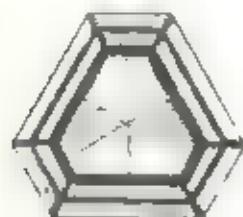
439. Optical Properties of Crystals Aggregates. The special optical phenomena of the different types of crystals aggregates (Fig. 646) and the extent to which they are affected by the same can be determined, depending upon the nature of the development of the minerals and their relative orientation. The case of ordinary granu-

This subject has been minutely studied by many investigators in recent years and important additions have been made to it both on the practical and the theoretical side. The results are, though doubtless ones still remain, many of the typical ones have found a satisfactory explanation. No single theory, however, can be universally applied.

The first question involved has been whether the anomalies are to be considered as secondary and non-essential, or whether they belong to the inherent atomic structure of the crystals in question. On the one hand, it has been argued that in small irregular surfaces, as Fig. 440, to cut out double refraction in isotropic substances or in optically uniaxial crystals the typical optical structure of a biaxial crystal. On the other hand, it is equally clear that even in thin plates some peculiarities in crystals in external form and at the same time in crystals of crystals, that they can occur. From a simple case, as that of argenteo-white, to more complex cases as witherite (Fig. 640). From the Figs. 641-644, particularly Figs. 428, 478-480, which last is sometimes peculiar. From thought optical study shows the monophase character of the material. Tensioning from a study of these cases. A similar was led, 1870, to the theory that the phenomena are caused in most cases, as explained by the absorption of a strain but still more, mainly to grouping of molecules which themselves will, if a well defined, of the same type of symmetry than that which most complex, where crystals actually simulate.

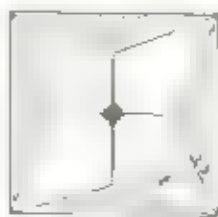
In regard to the two points of view mentioned, it seems probable that anterior, bearing in mind the expression, seen on cooling, or rather, of growth, it can be safely assumed to explain the optical character of many specimens in and, but a few, quartz. Again it has been fully proved that the later growth of a crystal, or rather, of a crystal, is a process of growth, of optical anomalies, from a process, as the reference to Bragg. An interesting example. The same, as of a specimen, was a very investigation, by the method of the first, of a series of, or polarization, but a present explanation to be, as in the one, Fig. 644, or in Bragg.

643



Alon. 111

645



Argenteo-white, 001

647



Laurite, 001

shows the appearance in polarized light of a section, of 111, from a crystal in which the successive layers have different composition. Further, according to Bragg, the optical peculiarities of many other species may be referred to this same cause. He remarks that particularly these cases (as with some garnets

* Crystals showing such peculiarities of highly complex type are called *manic* crystals.
by The Institute.

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IV. CHARACTERS DEPENDING UPON HEAT

442. The most important of the special properties of individual species with respect to heat is their solubility in the liquid phase and expansion, especially in their relation to crystallization, that is to say, their behavior with change of temperature, especially in the case of alternance of power of retaining heat and cold. The first two parts of these and other related subjects lies outside of the range of an *elementary* text-book. A few important facts are given upon heat, and beyond these references may be made to text-books on Physics and to special treatises, some of which are mentioned in the literature p. 351.

443. Fusibility. The approximate melting points of different minerals are an important character in distinguishing different species from one another by means of the microscope. For this purpose a series of carefully used for comparison, as explained in the literature devoted to this subject. Accurate determinations of the fusibility are difficult and though of little importance for the above object, they are interesting from a theoretical standpoint. They have been determined by various authors by the use of a number of different methods. The following are the approximate melting-

same values for the minerals used in von Kobell's case. Ar 504. Silicate, α -quartzite, 0.65; anorthite, 1200; anorthite, 1200; orthoclase, 1200; opalite, 1380; also for quartz, about 1600.

444. Conductivity. The conducting power of different crystallized media was early investigated by Senarmont. He observed, among other things, under investigation with wax and observed the form of the figure formed by a hot wire placed in contact with the surface of a crystal plate. Later investigations have been made by Röntgen, who collected a great deal of information. In general, the different crystallized minerals, as regards their thermal conductivity, crystallize to be divided into the three classes noted on p. 256. In other words, the conductivity for heat seems to follow the same general law as the propagation of light. It is to be seen, however, that experiments by S. P. Thompson and O. F. Long have shown a different rate of conductivity in minerals in the opposite directions of the vertical axis.

445. Expansion. Expansion, that is, increase in volume upon rise of temperature, is a nearly universal property for all solids. The amount of volume for one unit volume expanding from 0 to 1°C is called the coefficient of expansion. This quantity has been determined for a number of species. Further, the relative expansion in different directions is found to obey the same law as the light propagation. Crystals, as regards expansion, crystallize into the same three classes mentioned on p. 256 and assigned to in the preceding article.

The amount of expansion varies widely, and, as shown by Lamont, is enhanced particularly by the change. Muscovite, for example, crystallizes with a dilatation of 8.17 on the angle of the rhombohedron of passing from 0 to 100°C ; the form thus approaching that of a cube as the temperature increases. The dilatation is 0.46 volume for the same range of temperature, 0 minutes to 45°C , and arrangements for a rise in temperature from 25°C to 100°C , the angle of the prism dimension 2.46. In some rhombohedrons the angle of the vertical axis is lengthened and the horizontal shortened, whereas, others, the contrary the reverse is true. The variation is in both cases that the birefringence is diminished with the increase of temperature, for quartz possesses negative double refraction and quartz, positive.

It is to be noted that in general the expansion by heat with a rise in temperature is composed of crystals. For each case of the increase in temperature, the expansion is the same as the crystalline system. In other cases, however, the effect of heat may be to give rise to two different directions of expansion or to cause a rise in expansion in all directions. If crystals have axes of expansion, the expansion is the same as the crystalline system. Ar 441. Quartz, for example, will expand in all directions equally, as will also opalite and orthoclase. The former is said to expand in all directions equally. The expansion of crystals produced by heat has already been treated Ar 434.

446. Specific Heat. The specific heat of any substance is the amount of heat necessary to raise the temperature of one gram of the substance one degree Celsius. The amount of specific heat is the same necessary to raise one gram of water one degree Celsius. Later, in the section on specific heat, of many minerals have been made by Joly, by Forbes, and others. Some of the results reached are as follows:

	Joly	Oeberg		Joly	Oeberg
Quartz, cryst.	0.0541		Orthoclase	0.1869	0.27
Orthoclase	0.171	0.120	Albite	0.1983	0.270
Albite	0.1306		Amphibole, black	0.303	Augite 0.58
Diopside	0.1683	0.1445	Beryl	0.3008	0.474
Calc. A. calcrypt. 0.1780	0.176	0.1735	Calc. A. 0.2031	0.344	0.3012
Episide	0.1877	0.2861	Argonite	0.2036	

447 Diathermancy - Besides the slow molecular propagation of heat in a body measured by its thermal conductivity there is also to be considered the rapid propagation of what is called radiant heat through it by the wave-motion of the ether which surround it is molecules. This is merely a part of the general subject of light-propagation and is not discussed since heat-waves in the restricted sense differ from light waves only in their relative greater length. The degree of absorption exerted by the body is measured by its diathermancy, which corresponds to transparency in light. In this sense quartz, sylvite and fluorite are highly diathermancy some have almost but little of the heat waves passing through them, on the other hand gypsum and alumina absorb comparatively othermancy since while transparent to the short light-waves they absorb the long heat-waves, transforming the energy in a heat of sensible heat. Measurements of the diathermancy were easily made by Michelson, later by Tynall, Langley and others.

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V. CHARACTERS DEPENDING UPON ELECTRICITY AND MAGNETISM

I. ELECTRICITY

448 Electrical Conductivity — The subject of the relative conducting power of different substances is not of great interest.* In general these may be arranged, having a more or less increasing the regularity, in the following order of conductors: (1) the noble metals, which show perfect metallic phenomena; (2) the alloys and compounds of these elements; (3) the pure elements of the metallic class; (4) the electrolytes; (5) the non-electrolytes. In the case of the electrolytes the conductivity of such systems varies with the concentration conforming to the same law that governs the diffusion of a substance, for instance, it has been found that the conductivity of a solution of sodium sulphate is increased about 100 per cent. when twice the amount of the electrolyte is added to the solution.

449 Frictional Electricity — The development of an electrical charge on a body both by friction and by other ways. All the systems of electric induction, being the basis of what is commonly known as static electricity, are due to the rubbing of two bodies together, thus producing and separating electricities. For both cases, however, they be produced by different causes, of which some species, and by the same species in different cases. The groups are arranged positively and negatively, and positive, the one however existing positively or negatively with respect to the other. It is worthy of notice that the electricity of ether upon matter was early observed only when it does the Greek name *electrum* (deriving its rise to the word *electricity*).

450 Pyroelectricity — The simultaneous development of positive and negative charges of electricity on different parts of the same crystal when its parts are mutually rubbed or heated pyroelectricity. A crystal of a compound substance charged on one portion being warmed, a negative charge will be developed at one symmetrical point being cooled and a positive charge will be developed at the pyroelectric. This pyroelectricity was first observed in the case of tourmaline, which is rhombohedral in form in crystals, and in which a particularly marked and crystal belonging to groups of crystals few symmetry, especially those of its hexagonal type. It is worthy of notice, only with positive factors. The subject was early investigated by Ruse and Rose (1813), later by Barke, also by Brewster, Kunze, and others, and others.

In all cases it is true that destruction of the crystallographic symmetry causes charges of one sign, while under these conditions the opposite charges will be developed on the other face of the crystal. A few of the many possible examples will serve to bring out the most essential points.

Rhombohedral tourmaline (p. 83) assuming six axes of electricity in the set of tetrahedral faces and electricity on the other (Fig. 64).

Tetragonal rhombic tourmaline (p. 126) shows opposite charges at the opposite extremities of the vertical axis corresponding to the hexagonal crystal system. In this and in other similar cases the extremity which

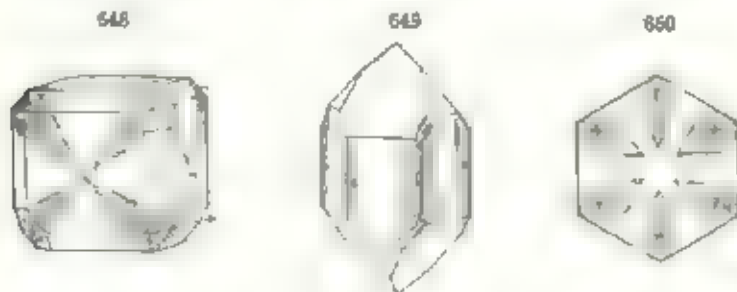
* On the conductivity of minerals, see Besprick, *Jb. Min.* [1861] Bd. 11, 403, 1868.

becomes positive on heating has been called the *analogous pole*, and that which becomes negative has been called the *antalogous pole*.

Quartz and *arsenic* with rhombohedral forms, p. 144, exhibit phenomena analogous to that of *calcite*.

Quartz in the rhombohedral form, p. 125 shows + electricity on heating in the three cleavage prism faces and - electricity at the three remaining cleavage faces. In the right-hand crystals the polarity is opposite to that of reflected. Twins may exhibit a high degree of complexity. Cf. Figs. 640, 650.

Calcite (melting p. 162), when heated to 120° or 130° , has an analogous pole faces and those at the solid angle rr' , the antalogous pole at the angle $mr'M'$ near plane n .



A very convenient and simple method for investigating the phenomena is the following which is due to A. C. C. First, heat the crystal or section carefully and slowly, pass a weak current through the plane of an axis of length and then pass it through a plane of length. While cooling, a mixture of rock salt and LiCl , but finely pulverized and previously ignited & fused, is poured through a fine cloth from a syringe below. The positively charged, and lead contacts on the parts having a negative charge, and the negatively charged surface is those with a positive charge. This is illustrated by Figs. 648 and 649. The latter is a construction given by H. A. H. and others. Cf. Pl. III of *Crystals*, p. 199.

461 Piezoelectricity. In heating or cooling of a crystal to induce piezoelectric effects, volume change is necessary. Further, if a change in volume can be brought about by other means such as compression or expansion, similar electric charges result. The term *piezoelectricity* has not been given to a development of the real charge on a crystal set under pressure or in tension. Charges of opposite sign are produced by the two different operations. This piezoelectricity is most interesting when a relation can be established between the behavior exhibited and the molecular structure as compared with the all up and down, the up and down, etc.

This subject has been investigated by H. A. H. and others, and others, and especially, the work of Lord Kelvin and others. H. A. H. has also employed the term *thermoelectricity* or *thermoelectricity* for the phenomena of producing an electrical current by the influence of direct radiation. Quartz is a conspicuous example.

462 Thermoelectricity. The contact of two unlike metals in general results in electrifying one of them positively and the other negatively. If

further, the point of contact be heated while the other parts, connected with a wire, are kept cool. A continuous current (see next) shown, for example, by a suitable galvanometer — is set up at the expense of the heat-energy supplied. If, on the other hand, the point of junction is cooled a current is set up in the reverse direction. This phenomenon is called *thermoelectricity*, and two metals so connected constitute a thermoelectric couple. Either it is found that different conductors can be arranged in order in a table — a so-called thermoelectric series — according to the *direction* of the current set up on heating and according to the *electromotive force* of this current. Among the metals bismuth + and antimony - stand at the opposite ends of the series, the current passes through the connecting wire from antimony to bismuth.

This subject is so far important for mineralogy, as it was shown by Bunsen that the natural metallic sulphides stand further off in a series than bismuth and antimony, and consequently by them a higher electromotive force is induced. The thermoelectrical relations of a large number of minerals were determined by Flögel.

It was early observed that some minerals have varieties which are both + and -. Rose attempted to establish a relation between the positive and negative pyrochroal forms of pyrite and cobaltite, and the positive or negative thermoelectrical character. Later investigations by Schrauf and Dana have shown, however, that the same peculiarity belongs also to gausestoe, cerussite, skutterudite, danabite, and other minerals, and it is demonstrated by them that it cannot be dependent upon crystalline form, but rather upon chemical composition.

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* See Luederich, *Phys. Kristallographie*, 1891, for a full discussion of the topics briefly touched upon in the preceding pages, also for references to original articles, also Tutton, *Crystallography and Practical Crystal Measurement*, Vol. 2, chapter 49, 1922.

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VI. TASTE AND ODOR

In their action upon the senses a few minerals possess taste, and others odor, some of them possessing both.

456. Taste belongs only to metallic minerals. The different kinds of taste adapted for reference are as follows:

1. *Astringent*: the taste of vitriol.
2. *Nervous astringent*: taste of alum.
3. *Saline*: taste of common salt.
4. *Alkaline*: taste of soda.
5. *Cooling*: taste of sulphate.
6. *Bitter*: taste of Epsom salts.
7. *Sour*: taste of sulphuric acid.

457. Odor. Excepting a few gaseous and soluble species, minerals in the very unchanged state do not give off odor. By friction, heating with fire, or wetting, the decomposition of some volatile ingredients by heat or acids, elements not new to the mind which are thus designated:

1. *Alliacious*: the odor of garlic. Produced by arsenic, antimony, etc. This odor, it may now be deduced from arsenical compounds, with use of heat.
2. *Hydrocyanic odor*: the odor of acryling, hydrocyanic. This odor is strongly perceived when the crystals are heated.

3. *Sulphureous*: from the sulphur from pyrite, and from many other ores.

4. *Bituminous*: the odor of bitumen.

5. *Fetid*: the odor of sulphuretted hydrogen or rotten eggs. It is elicited by friction from some varieties of quartz and limestone.

6. *Tergateous*: the odor of argillaceous clay. It is obtained from serpentine and some siliceous minerals, by heating them with a brown oil, others, as pyrite, afford it when heated.

458. Feel. The term is a character which is necessary of some importance to mind to be smooth and soft, greasy, etc. Some minerals, by reason of their hygroscopic character, adhere to the tongue when brought in contact with it.

Of the elements, oxygen, hydrogen, nitrogen, chlorine, and fluorine are gases, iron, nickel, and cobalt are liquids, mercury is also a liquid, but the others are solids under ordinary conditions.

O = 16			O = 16		
Symbol	At. Weight		Symbol	At. Weight	
Aluminum	Al	27.0	Mercury	Hg	200.6
Antimony	Sb	121.7	Molybdenum	M	95.9
Argon	Ar	39.9	Neodymium	Nd	144.2
Arsenic	As	74.9	Nickel	Ni	58.7
Bismuth	Bi	208.9	Niobium	Nb	92.9
Boron	B	10.8	Nitrogen	N	14.0
Bromine	Br	79.9	Osmium	Os	190.5
Calcium	Ca	40.0	Oxygen	O	16.0
Carbon	C	12.0	Palladium	Pd	106.7
Cerium	Ce	140.1	Phosphorus	P	31.0
Chlorine	Cl	35.5	Platinum	Pt	195.1
Cobalt	Co	58.9	Plutonium	Pu	244.0
Copper	Cu	63.5	Praseodymium	Pr	140.9
Dysprosium	Dy	162.5	Radium	Ra	226.0
Erbium	Er	167.3	Rhenium	Rh	186.2
Eurium	Eu	151.9	Rhodium	Rd	101.1
Ferbium	Fm	150.0	Rubidium	Rb	85.4
Gadolinium	Gd	157.2	Samarium	Sm	150.4
Germanium	Ge	72.6	Selenium	Se	78.9
Gallium	Ga	69.7	Silver	Ag	107.9
Helium	He	4.0	Silver	Ag	107.9
Hydrogen	H	1.0	Silver	Ag	107.9
Iodine	I	126.9	Silver	Ag	107.9
Iridium	Ir	192.2	Silver	Ag	107.9
Iron	Fe	55.8	Silver	Ag	107.9
Krypton	Kr	83.8	Silver	Ag	107.9
Lanthanum	La	138.9	Silver	Ag	107.9
Lead	Pb	207.2	Silver	Ag	107.9
Lithium	Li	6.9	Silver	Ag	107.9
Mercury	Hg	200.6	Silver	Ag	107.9
Magnesium	Mg	24.3	Silver	Ag	107.9
Manganese	Mn	54.9	Silver	Ag	107.9

466. Metals and Non-metals. The elements may be divided into two main or less distinct classes the metals and the non-metals. Between the two is a number of elements sometimes called the semi-metals. The metals, as gold, silver, iron, sodium, are those elements which, physically described, possess to a more or less perfect degree the fundamental characters of the ideal metal, viz. malleability, ductility, metallic luster and opacity to light, conductivity for heat and electricity. Moreover, chemically described, they commonly play the part of the positive or basic element in a simple compound. (As later defined Arts. 474-477). The non-metals, as sulphur,

those which, etc., and the gases hydrogen, chlorine, etc., have none of the above characters, and so they are called simple. The true acids and bases are poor indicators for the study of chemistry. They are, however, essential to a knowledge of the nature of acids and bases.

The same is true of the elements which are called simple. They are, however, essential to a knowledge of the nature of acids and bases. They are, however, essential to a knowledge of the nature of acids and bases. They are, however, essential to a knowledge of the nature of acids and bases.

It is to be understood that the above is a very general statement of the nature of acids and bases. It is not intended to imply that the above is a complete statement of the nature of acids and bases. It is not intended to imply that the above is a complete statement of the nature of acids and bases.

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466 Positive and Negative Elements. It is common to make a distinction between positive and negative elements. This is done on the basis of the nature of the elements. Positive elements are those which are found in the positive state, and negative elements are those which are found in the negative state.

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467 Periodic Law. It is to be understood that the above is a very general statement of the nature of acids and bases. It is not intended to imply that the above is a complete statement of the nature of acids and bases. It is not intended to imply that the above is a complete statement of the nature of acids and bases.

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TABLE OF THERMOCALASSIFICATION OF THE ELEMENTS

I	II	III	IV	V	VI	VII	VIII
1 H 1.008	2 He 4.003	3 Li 6.941	4 Be 9.012	5 B 10.811	6 C 12.011	7 N 14.007	8 O 16.000
9 F 18.998	10 Ne 20.183	11 Na 22.990	12 Mg 24.305	13 Al 26.982	14 Si 28.086	15 P 30.974	16 S 32.065
17 Cl 35.453	18 Ar 39.948	19 K 39.098	20 Ca 40.078	21 Sc 44.956	22 Ti 47.88	23 V 50.942	24 Cr 52.004
25 Mn 54.938	26 Fe 55.847	27 Co 58.933	28 Ni 58.69	29 Cu 63.546	30 Zn 65.38	31 Ga 69.723	32 Ge 72.63
33 As 74.922	34 Se 77.94	35 Br 79.904	36 Kr 83.80	37 Rb 85.468	38 Sr 87.62	39 Y 88.906	40 Zr 91.224
41 Nb 92.906	42 Mo 95.94	43 Tc 98.906	44 Ru 101.07	45 Rh 102.905	46 Pd 106.36	47 Ag 107.868	48 Cd 112.411
49 In 114.818	50 Sn 118.710	51 Sb 121.757	52 Te 127.6	53 I 126.905	54 Xe 131.29	55 Ba 137.327	56 La 138.905
57 Ce 140.12	58 Pr 140.908	59 Nd 144.24	60 Pm 144.913	61 Sm 150.36	62 Eu 151.964	63 Gd 157.25	64 Tb 158.925
65 Dy 162.50	66 Ho 164.930	67 Er 167.259	68 Tm 168.933	69 Yb 173.045	70 Lu 174.967	71 Hf 178.49	72 Ta 180.948
73 W 183.84	74 Re 186.207	75 Os 190.23	76 Ir 192.22	77 Pt 195.084	78 Au 196.967	79 Hg 200.59	80 Tl 204.384
81 Pb 207.2	82 Bi 208.980	83 Po 209	84 At 210	85 Rn 222	86 Fr 223	87 Ra 226	88 Ac 227
89 Th 232.038	90 Pa 231.036	91 U 238.029	92 Np 237.048	93 Pu 239.052	94 Am 243.061	95 Cm 247.070	96 Bk 247.070
97 Cf 251.08	98 Es 252.083	99 Fm 257.10	100 Md 258.10	101 No 259.10	102 Lr 262.10	103 La 262.10	104 Ce 262.10

oxides. Here belong Cu_2S cuprous sulphide (chalcocite), ZnS zinc sulphide (sphalerite), PbFeS_4 iron pyrite (cubite), FeS_2 iron disulphide (pyrite), S_8 native sulphur, etc.

474. Acids. The most complex chemical compound is an understanding of which is needed in a study of minerals are classes as acids, bases, and salts, the distinctions between them are important.

An *acid* is a compound of hydrogen, or hydroxy, with a non-metallic element, as chlorine, sulphur, nitrogen, phosphorus, etc., or a radical containing these elements. When dissolved in water they all give a positive hydrogen ion and a negative ion substance such as $\text{Cl}^-\text{SO}_4^{2-}$, etc. The hydrogen atom of an acid may be replaced by metallic atoms, the result being then the formation of a salt (see Art. 478). Acids turn blue litmus paper red and give a sharp, sour taste. The following are familiar examples:

HCl , hydrochloric acid,
 HNO_3 , nitric acid,
 H_2CO_3 , carbonic acid,
 H_2SO_4 , sulphuric acid,
 H_3BO_3 , boric acid,
 H_3PO_4 , phosphoric acid,
 H_2SiO_4 , orthosilicic acid.

It is to be noted that with a given acid element several acids are possible. Thus normal, or orthosilicic, acid is H_2SiO_4 in which the bonds of the element silicon are all satisfied by the hydroxyl HO . But the removal of one molecule of water, H_2O , from this gives the formula H_2SiO_3 , or metasilicic acid.

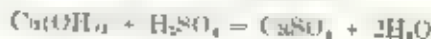
Acids which, like HNO_3 , contain one atom of hydrogen that may be replaced by a metallic atom (e.g. in KNO_3) are called *monobasic*. If, as in H_2CO_3 and H_2SO_4 , there are two atoms or a single bivalent atom (e.g. in CaCO_3 , BaSO_4), the acids are *dibasic*. Similarly, H_3PO_4 is *tribasic*, etc.

Most acids are liquids or gases, and hence acids are represented very sparingly among minerals. B(OH)_3 , boric acid (exsiccite), is an exception.

475. Bases. The *bases* or hydroxides, as they are now called, are compounds which may be regarded as a metal in a metallic element or radical, and the univalent radical hydroxyl, OH , or in other words, of an oxide with water. They are compounds which in solution yield hydroxyl ions. Thus potash, K_2O , and water H_2O form 2KOH , or potash in hydroxide form. CaO and H_2O similarly give Ca(OH)_2 , or calcium hydroxide. In general, when soluble in water, bases give in solution a reaction with turn-moss paper or red litmus paper, and they also neutralize acids as explained in the next article. For further the bases and water or aqueous, that is, at a temperature sufficiently high to break up the compound.

Among minerals the bases are represented by the hydroxides, or hydrated oxides, as Mg(OH)_2 , magnesium hydroxide (serpentine), Al(OH)_3 , aluminium hydroxide (gibbsite), also $\text{Al}_2(\text{OH})_6$ (diaspore), etc.

476. Salts. A third class of compounds are the salts; these may be regarded as formed chemically by the reaction of a base upon an acid, or, in other words, by the neutralization of the acid. Thus calcium hydroxide and sulphuric acid give calcium sulphate and water.



Here calcium sulphate is the salt, and in this case the acid sulphuric acid is said to be neutralized by the base, calcium hydroxide. It is important to compare the formulae of a base, an acid, and the corresponding salt as follows:



Here it is seen that a salt may be simply described as formed from an acid by the replacement of the hydrogen atoms, or atoms, by a metallic element or radical.

477. Typical Salts. The commonest types of salts represented among minerals are the following:

Chlorides—salts of hydrochloric acid, HCl , as AgCl , silver chloride (cerargyrite).

Nitrates—salts of nitric acid, HNO_3 , as KNO_3 , potassium nitrate (niter).

Carbonates—salts of carbonic acid, H_2CO_3 , as CaCO_3 , calcium carbonate (calcite and aragonite).

Sulphates—salts of sulphuric acid, H_2SO_4 , as CaSO_4 , calcium sulphate (anhydrite).

Phosphates—salts of phosphoric acid, H_3PO_4 , as $\text{Ca}_3(\text{PO}_4)_2$, calcium phosphate.

Silicates—several classes of salts are here included. The most common are the salts of orthosilicic acid, H_4SiO_4 , as MgSiO_3 , magnesian orthosilicate (rhodonite). Also salts of orthosilicic acid, H_2SiO_3 , as MgSiO_3 , magnesian orthosilicate (tephroite).

Numerous other classes of salts are also included among mineral species, their composition as well as that of complex salts of the above types, is explained in the descriptive part of this work.

478. Normal, Acid, and Basic Salts.—A neutral or normal salt is one in which the basic and acidic elements have completely reacted together, or in other words, in the type already given as examples in which all the hydrogen atoms of the acid have been replaced by metallic atoms or radicals, or the hydroxyl groups have been completely replaced by the acid radical. Thus K_2SO_4 is normal potassium sulphate, but H_2KSO_4 , on the other hand, is acid potassium sulphate, since in the acid H_2SO_4 only one of the hydrogens is taken by the basic element potassium. Salts of this kind are called *acid salts*. The formula in such cases may be written* as if the compound consisted of a normal salt taken as a whole, thus for the example given H_2KSO_4 , H_2SO_4 .

A *basic salt* is one in which the acid part of the compound is not sufficient to satisfy all the needs of the base. Thus malachite is a basic salt, basic carbonate of copper—its composition being expressed by the formula $\text{Cu}_2(\text{OH})_2\text{CO}_3$. This may be written $\text{CuCO}_3 \cdot \text{Cu(OH)}_2$, or $(\text{Cu})_2 = \text{CO}_3 + \text{OH}$.

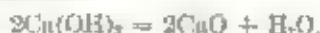
The majority of minerals consist not of simple salts, as has been stated above, but of more or less complex double salts in which several different elements are present. Thus common greenish garnet is an orthosilicate containing both calcium and aluminium as bases, its formula is $\text{Ca}_2\text{Al}_2\text{Si}_2\text{O}_{10}$.

479. Sulpho-salts.—The salts thus far spoken of are all oxygen salts. There are not others, of any great constitution, in which sulphur takes the place of the oxygen; they are, since called *sulpho-salts*. Thus iron sulphide

* This may vary from writing the compound as follows: the name often given to the compound, name of the acid, neutral, basic or acid.

arsenious acid has the formula H_3AsO_3 and the corresponding silver salt is Ag_3AsO_3 , the mineral pyroaurite. Similarly the silver salt of the analogous antimony acid is Ag_3SbO_3 , the mineral pyrosbomite. From the normal series is named a series of other hypobasic acids and their silver derivatives, such as HAsS_2 , H_2AsS_3 , etc., these acids are not known to exist and their salts are important minerals. Thus zincite, PbSb_2S_4 , is a salt of the acid $\text{H}_2\text{Sb}_2\text{S}_4$, and jamesonite, $\text{Pb}_4\text{Sb}_2\text{S}_{11}$, of the acid $\text{H}_4\text{Sb}_2\text{S}_{11}$, etc.

480. Water of Crystallization. As stated in Art. 475 the hydroxides, or bases, and under basic salts, generally, add water when ignited. Thus copper hydroxide, $\text{Cu}(\text{OH})_2$, breaks up on heating into CuO and H_2O , as expressed in the equation:



So, also, the basic cupric carbonate, malachite, $\text{Cu}(\text{OH})_2\text{CO}_3$, yields water on ignition, and the same is true of the complex basic or hypobasic salts, e.g., where formula is $\text{H}(\text{O})_n\text{Cu}_m\text{As}_n\text{SO}_4$. It must be understood, however, in these circumstances, that water is such a present in the substance.

Of course, it must be that there is a large number of mineral compounds which yield water readily when heated, and the water in water molecules are regarded as present in the water of crystallization. Thus the formula of gypsum is written

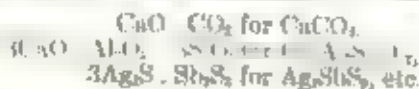


and the molecules of water, $2\text{H}_2\text{O}$, are considered as water of crystallization. So, too, in potash alum, $\text{KAl}(\text{SO}_4)_2 + 12\text{H}_2\text{O}$, the water is believed to play an active part.

481. Formulas of Minerals. The strictly empirical formula expresses the kinds and numbers of atoms of the elements present in the given compound without attempting to show the way in which they are believed that the atoms are combined. Thus, in the case of zircon, the empirical formula is $\text{HfO}_2\text{Al}_2\text{Si}_2\text{O}_{12}$. When it is tempting to represent the structural formula which will be discussed here, it is convenient to omit or to indicate the atoms when there is reason to believe they are present in a certain number. Thus the same formula, written $\text{Hf}(\text{O})_2\text{Al}(\text{SiO}_4)_2$, is written for it is regarded as a case of crystallization, rather than a basic salt of phosphoric acid, H_2SiO_4 .

Again, the empirical formula of common apatite is $\text{Ca}_5(\text{PO}_4)_3\text{F}$, but if this is written $\text{Ca}_5(\text{O})_3(\text{PO}_4)_3$, because of the presence of a hydroxyl group of the acid HPO_4 , that is, H_2PO_4 , in which a half hydrogen atom is represented by four O atoms together with the oxygen radical of O. In another kind of apatite the radical Cl enters in the same way. Similarly for the formula of pyromorphite is $\text{Pb}_3(\text{Pb})_2(\text{PO}_4)_6$ and carlockite $(\text{Pb})_4(\text{Pb})_2(\text{VO}_4)_6$.

Further, it is often convenient to employ the method of writing the formulas in vogue under the old nomenclature system. For example,



It is no longer believed, however, that the older radical groups CaO , AlO_3 , etc., actually exist in the molecule of the substance. But in practice these

groups are what analysis of the substance affords directly, and in part because so easily retained in the memory, this method of writing is still often used.

482. Calculation of a Formula from an Analysis.—The result of an analysis gives the proportions, in a hundred parts of the mineral, of each of the elements themselves or of their oxides or other compounds obtained in the chemical analysis. In order to obtain the atomic proportions of the elements

Divide the percentages of the elements by the respective atomic weights, or, for those of the oxides, divide the percentage amounts of each by their molecular weights, then find the simplest ratio in whole numbers for the numbers thus obtained.

Example.—An analysis of hematite from Wolfberg gave C. Brongniart the results in the following. These percentages are— Fe 69.9, O 30.1. Divide these percentages by the atomic weights of Fe and O , and the results are— Fe 1.25, O 1.875. Divide these numbers by the smallest number, 1.25, and the results are— Fe 1, O 1.5. Hence the formula derived is Fe_2O_3 . (The theoretical values called for by the formula are found under 4.)

	(1)	(2)	(3)	(4)
Fe	$24.34 \div 56 = 0.435$		1	24.7
O	$19.76 \div 8 = 2.47$	$= 0.617$	3	19.8
Pb	$42.88 \div 207.2 = 0.207$		1	42.5
Cu	$13.06 \div 63.5 = 0.207$		1	13.0
	100.04			100.0

Second Example.—The mean of two analyses of a garnet from Alaska gave Brongniart the results in the following. These percentages are— SiO_2 39.29, Al_2O_3 31.70, FeO 30.82, MnO 1.51, MgO 5.26, CaO 1.90. Divide these percentages by the molecular weights of these oxides, and the results are— SiO_2 0.655, Al_2O_3 0.212, FeO 0.439, MnO 0.022, MgO 0.102, CaO 0.036. Divide these numbers by the smallest number, 0.022, and the results are— SiO_2 30.2, Al_2O_3 9.6, FeO 20.0, MnO 1.0, MgO 4.6, CaO 1.6. Hence the formula derived is $\text{Si}_3\text{O}_{10}\text{Al}_9\text{Fe}_{20}\text{Mn}\text{Mg}_5\text{Ca}_2$. (The theoretical values called for by the formula are found under 4.)

	(1)	(2)	(3)	(4)
SiO_2	$39.29 \div 60 = 0.655$			30.2
Al_2O_3	$31.70 \div 102 = 0.212$			9.6
FeO	$30.82 \div 71.9 = 0.439$			20.0
MnO	$1.51 \div 70.9 = 0.022$			1.0
MgO	$5.26 \div 40 = 0.132$			4.6
CaO	$1.90 \div 55.9 = 0.036$			1.6
	100.57			

It is necessary, when very small amounts only of certain elements, as Al_2O_3 , MgO , CaO , are present to neglect them in the formula, reckoning the results on the basis of the elements which they replace, thus, with Fe in the case of the garnet just given. The degree of correspondence between the analysis and the formula is, of course, if the latter is correct, measured, in large measure, upon the accuracy of the former.

483. Isomorphism.—Isomorphous compounds which have an analogous composition and a closely related crystaline form are customarily said to be isomorphous. This phenomenon, called isomorphism, was first clearly brought out by Mitscherlich.

Many examples of groups of isomorphous compounds will be found among the minerals described in the following pages. Some examples are mentioned here in order to elucidate the subject.

In the brief discussion of the periodic classification of the chemical elements of Art. 467, attention has been called to the prominent groups among

the elements which form analogous compounds. These calcium, barium, and strontium, however, also form the two series of analogous compounds,

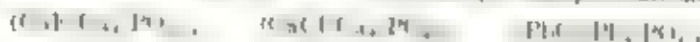
Aragonite Group		Barite Group	
$\text{Ca}(\text{CO}_3)$, aragonite	Also	CaSO_4 , anhydrite	
$\text{Ba}(\text{CO}_3)$, witherite		BaSO_4 , barite	
$\text{Sr}(\text{CO}_3)$, strontianite		SrSO_4 , celestine	
$\text{Pb}(\text{CO}_3)$, cerussite		PbSO_4 , anglesite	

Further, the members of each series crystallize in the same similar forms. The *aragonite* group is characterized with axes in the ratio of 1 to 1.20, and corresponding to this the crystals are hexagonal forms due to twinning. The *barite* group also forms similar hexagonal forms and though the axes deviates somewhat from the others, it is close together in ratio, 1 to 1.40, are.

Again, even though all the members of these groups form a series of variations with the general composition as shown in the list of the specimens of the *barite* group, each compound. This factor brings out clearly the close relation in form between the species names.

Further, it is generally true with a non-crystallous series that the various members vary in degree or less degree of the composition of one of the two series, the series without causing any marked change in the crystal characters. For instance, in the *barite* group, celestine may contain small percentages of $\text{Mg}(\text{CO}_3)$, $\text{Fe}(\text{CO}_3)$, and $\text{Mn}(\text{CO}_3)$. These different members may assume the crystal form of the material the same but because the composition is slightly different, $\text{Mg}(\text{CO}_3)$ and $\text{Fe}(\text{CO}_3)$ may replace each other in any proportion and the same is true with celestine and strontianite. $\text{Mg}(\text{CO}_3)$, $\text{Fe}(\text{CO}_3)$, and $\text{Mn}(\text{CO}_3)$ mixtures of these latter members do have two properties and give rise to a series of which different forms have been assigned. It is found that some of these compounds have a more extensive similarity in form and composition to be compared with a series that are between the end members, $\text{Pb}(\text{CO}_3)$ and $\text{Ca}(\text{CO}_3)$, to that found in a certain compound, but no isomorphism exists between $\text{Ca}(\text{CO}_3)$ and $\text{Mg}(\text{CO}_3)$. However, certain varying amounts of $\text{Fe}(\text{CO}_3)$, $\text{Mn}(\text{CO}_3)$ and an excess of $\text{Ca}(\text{CO}_3)$ or $\text{Mg}(\text{CO}_3)$ which enter the regular structure in the form of isomorphous replacements.

The *barite* group forms another valuable illustration since it is represented by the analogous compounds, CaSO_4 , BaSO_4 , SrSO_4 , and PbSO_4 . These four compounds are isomorphous and crystallize in the same form, but because the composition is slightly different, CaSO_4 and BaSO_4 may replace each other in any proportion and the same is true with celestine and strontianite. $\text{Mg}(\text{CO}_3)$ and $\text{Fe}(\text{CO}_3)$ mixtures of these latter members do have two properties and give rise to a series of which different forms have been assigned. It is found that some of these compounds have a more extensive similarity in form and composition to be compared with a series that are between the end members, $\text{Pb}(\text{CO}_3)$ and $\text{Ca}(\text{CO}_3)$, to that found in a certain compound, but no isomorphism exists between $\text{Ca}(\text{CO}_3)$ and $\text{Mg}(\text{CO}_3)$. However, certain varying amounts of $\text{Fe}(\text{CO}_3)$, $\text{Mn}(\text{CO}_3)$ and an excess of $\text{Ca}(\text{CO}_3)$ or $\text{Mg}(\text{CO}_3)$ which enter the regular structure in the form of isomorphous replacements.



Some of the more recent mineralogical groups are mentioned in the list of the specimens of the *barite* group, each compound. This factor brings out clearly the close relation in form between the species names. Further, it is generally true with a non-crystallous series that the various members vary in degree or less degree of the composition of one of the two series, the series without causing any marked change in the crystal characters. For instance, in the *barite* group, celestine may contain small percentages of $\text{Mg}(\text{CO}_3)$, $\text{Fe}(\text{CO}_3)$, and $\text{Mn}(\text{CO}_3)$. These different members may assume the crystal form of the material the same but because the composition is slightly different, $\text{Mg}(\text{CO}_3)$ and $\text{Fe}(\text{CO}_3)$ may replace each other in any proportion and the same is true with celestine and strontianite. $\text{Mg}(\text{CO}_3)$, $\text{Fe}(\text{CO}_3)$, and $\text{Mn}(\text{CO}_3)$ mixtures of these latter members do have two properties and give rise to a series of which different forms have been assigned. It is found that some of these compounds have a more extensive similarity in form and composition to be compared with a series that are between the end members, $\text{Pb}(\text{CO}_3)$ and $\text{Ca}(\text{CO}_3)$, to that found in a certain compound, but no isomorphism exists between $\text{Ca}(\text{CO}_3)$ and $\text{Mg}(\text{CO}_3)$. However, certain varying amounts of $\text{Fe}(\text{CO}_3)$, $\text{Mn}(\text{CO}_3)$ and an excess of $\text{Ca}(\text{CO}_3)$ or $\text{Mg}(\text{CO}_3)$ which enter the regular structure in the form of isomorphous replacements.

Further, the Feldspar Group in the broader sense includes several other species, conspicuously the monoclinic orthoclase KAlSi_3O_8 , which, though belonging to a different system, still approximates closely in form to the triclinic species.

485. Variation in Composition of Minerals. Isomorphous Replacement and Solid Solution. The fact that a mineral must rigidly conform in its chemical composition to a theoretical composition derived from its formula is no longer to be strictly held. It is true that the majority of minerals do show a close correspondence to that theory, occasionally within the limits of possible errors in the analyses. On the other hand, many minerals show slight and certain ones considerable variations from their theoretical compositions. These variations may be explained by the principle of isomorphism. An excellent example is the case of sphalerite. As soon as the analyses of steel bodies show the percentages of zinc diminish and those of iron correspondingly increase, it is evident from these analyses that iron, and in a much smaller degree other metals, may enter into the chemical compound and while replacing the zinc perform the same function as it, in the crystal lattice structure of the mineral. The iron is therefore spoken of as being isomorphous with the zinc or the iron sulphide may be regarded as a variety with the zinc sulphide molecule. There is no definite ratio between the amounts of the iron and zinc that may be present but there is a constant ratio (1:1) between the sum of the amounts of the metals and the amount of sulphur. That is, although the composition may vary, the atomic ratios and the crystalline structure remain constant. In some cases this interchange between elements or radicals may be complete, in other cases there may be distinct limitations to the amount by which any element or radical may be replaced by another. For instance in sphalerite the maximum percentage of the isomorphous iron seems to be about 16 to 18 per cent.

Colorado Sphalerite

S	32.23
Zn	68.69
Fe	0.12
	100.04

Brown Sphalerite

S	33.30
Zn	63.36
Fe	3.90
	100.52

Bary Sphalerite

S	33.35
Zn	60.92
Fe	15.44
Cd	0.30
Pb	1.11
	100.02

Further, we have cases where a compound may, in a certain sense, dissolve another unrelated substance and form what is known as a *solid solution*. This kind of phenomenon is well recognized among artificial salts and has recently been definitely proved with regard to minerals. For instance, it has been shown experimentally that the artificial iron sulphide FeS , corresponding to pyrrhotite, can dissolve an excess of sulphur up to about 6 per cent. Natural pyrrhotite always contains an excess of sulphur over that required by the formula FeS and various formulas such as FeS , Fe_7S_{11} , etc. have been assigned to the mineral. This extra sulphur in the mineral varies in amount but always as its maximum about 6 per cent. In view of the experimental data there is no doubt but that pyrrhotite should be considered as the monosulphide of iron containing varying small amounts of excess sulphur in the form of a solid solution.

Another case of solid solution is undoubtedly shown by nephelite which commonly contains a small excess of SiO_2 . It is very probable that further

estimation will show that many numerals have the power of telling not only a certain amount of foreign money but also that there is a certain exchange discrepancy so that an even may be expected at any given rate of exchange, but for the more money we have, the more profit we will make. A small amount of discrepancy will result in a small loss, but a large discrepancy will result in a large loss.

[illegible]

These mineral grains are formed at low temperatures and pressures and are characteristic of the products of rock weathering and in the unaltered zone of outcrops. Several of them also occur in igneous rocks. These minerals are either monomineralic or polymineralic structures. When the concentrations of minerals do not permit free growth, they occur as inclusions. From a structural point of view, they become more complex than the host crystal through a secondary rearrangement and develop a texture of inclusion structure. They have been designated as *meta-igneous*.

One important character of the gel minerals is their power to absorb foreign materials. If, though, some change in constitution of these lyotropic gels should have a part of its water content, the crystalline minerals would have been fixed and porous structure existing adapted to exert a strong power of absorption. Consequently, addition of water to the main mass of the material may have a substantial increase in water content due to crystallized material. It will, however, show no considerable change in composition due both to the increase in volume of the crystallized water and to the secondary absorption of foreign particles, gases, substances derived from them, and so on. The rate of permeation varies with the rate of the physical and chemical changes, etc. As suggested above, various kinds of minerals that occur now in crystalline forms are thought to exist. For example, some authors speak of the rate as the gel form of lyotropic stevensonite as the gel form of goethite, the source of diopside and further give new names, such as gel-cerite, gel-sphenite, etc., to the gel phases of the corresponding crystalline minerals.

* For a summary of the subject of pre-nervals and a complete bibliography refer to the book by M. J. G. S. (1968) "Pre-nervals and their importance in the life of the insect".

CHEMICAL EXAMINATION OF MINERALS

492 The complete investigation of the chemical composition of a mineral includes first the determination of the elements present by qualitative analysis and, second, the determination of the relative amounts of each by quantitative analysis from which exact formulae can be calculated. Both processes carried out methodically for the equipment of a chemical laboratory. An approximate quantitative analysis, however, can in many cases, be made practically easily with few complications. The methods employed involve either the use of acids or other reagents 'a' the wet way or b) the use of a blowpipe or of both methods combined. Some practical instructions will be given applying to both cases.

EXAMINATION IN THE WET WAY

493. Reagents, etc. — The most commonly employed chemical reagents are the three mineral acids, namely, nitric, sulphuric and hydrochloric. To these may be added ammonium hydroxide and solutions of ferric chloride, silver nitrate, ammonium molybdate, ammonium oxalate, stannous chloride, distilled water in a wash-bottle.

A few test-tubes are needed for the trials and sometimes a porcelain dish with a handle when a casserole. Further, a glass funnel and filter-paper. The Bunsen gas-burner, provided it is the best source of heat, though unsuited for primary use as a gas.

In testing the powdered mineral with the acids the important points to be noted are: 1. the degree of solubility and 2. the phenomena attending complete or partial solution; that is, whether a residue is left and if so, whether without effervescence. If so, when a gas is evolved, producing effervescence, or if an insoluble substance is separated out.

494 Solubility. — In testing the degree of solubility in trichloroacetic acid and in aqua regia special thought is the case of many metallic minerals, as the nitrates and compounds of lead and silver nitrate acid is required. Tests of trichloroacetic acid and aqua regia (trichloroacetic acid) are resorted to.

The test is usually made in a test-tube and in general the fragment of mineral to be examined should be first carefully pulverized in an agate mortar. In most cases the heat of the Bunsen burner may be employed.

(a) Many minerals are not soluble in acids without effervescence. Among these are some of the oxides as hematite, magnetite, goethite, etc. Some sulphates, many phosphates and arsenates, etc. Lead and barium are soluble only in aqua regia or trichloroacetic acid.

A yellow solution is usually obtained if much iron is present, a blue or greenish blue solution turning deep blue on the addition of ammonia by discharge of excess from compounds of copper — pink or pale rose from cobalt, etc.

(b) Solubility with effervescence takes place when the mineral loses a gaseous ingredient, or when one is generated by the mutual reaction of acid and mineral. Most compounds here are the carbonates of which dissolve with effervescence, giving off the carbonic gas carbon dioxide (CO_2), though some of them only when pulverized, or again on the addition of heat. In applying this test dilute hydrochloric acid is employed.

Hydrogen sulphide (H_2S) is evolved by some sulphides when dissolved in hydrochloric acid; this is true of sphalerite, stannite, etc. This gas is easily recognized by its offensive odor.

Chlorine is evolved by oxides of manganese and also chromic acid, stannic acid when dissolved in hydrochloric acid.

Ammonia (NH_3) is given off in the form of red suffocating fumes from the residue in the flask, and also some of the lower oxides of phosphorus when treated with hydrochloric acid.

(c) The separation of all insoluble material takes place with many minerals, the silicates sometimes as a fine powder and again as a mass in the upper part of the flask, and is well to get the residue into a glass to test the point of the test by pulverizing some of the powder with strong hydrochloric acid, and the solution afterward slowly evaporated nearly to dryness. With a constant addition of acid the green color takes place and the residue left has not proved useful, while some others, when the residue is ground in a mortar and pestle is very heavy.

With many sulphides as pyrite, a separation of sulphur takes place when they are treated with hydrochloric acid.

Some compounds of uranium and tungsten are decomposed by hydrochloric acid with the separation of the oxides of the elements in question. With the same is true of salts of molybdenum and vanadic acids, they are here the oxides are soluble in an excess of the acid.

Compounds containing silver, lead and mercury give with hydrochloric acid a solution of the chlorides. These compounds are, however, soluble in nitric acid.

When compounds containing tin are treated with nitric acid the tin dissolves, such compounds as white powder. A corresponding reaction takes place under similar circumstances with minerals containing arsenic and antimony.

Insoluble Minerals—A large number of minerals are not so easily attacked by any of the acids. Among these may be named the following: oxides, corundum, spinel, chromite, ilmenite, rutile, cassiterite, quartz, microcassiterite, many varieties of garnets, zircon, and monazite. Some of the sulphates as barite, celestite, many phosphates, as xenotime, azurite, chlorite, malachite, also the arsenite, arsenate.

495 Examination of the Solution.—If the mineral is difficultly or only partially soluble, the question arises, is it or is not completely dissolved at once? Partial solution is detected when an excess given to the liquid or more generally by the precipitate formed from a sample of the solution of ammonium hydroxide to the liquid, is left from the remaining powder. The further examination of the solution is decided, whether it is a part of complete solution after the separation of the insoluble part, or not. It requires the examination of the solution by means of qualitative analysis.

It may be noted, however, that if the solution indicates the presence of sulphur as shown by the precipitation of a white white powder of arsenic sulphate (H_2SO_4) when barium chloride is added. The presence of arsenic is shown by the separation of a white easily precipitated silver chloride ($AgCl$) upon the addition of any chlorine compound. Conversely, the same procedure shows the presence of chlorine when silver nitrate is added to the solution.

Again, phosphorus may be detected if present, even in small quantity,

fragment of mineral between the platinum points at *d*. The steel points at the other end are used to pick up small pieces of minerals that must not be inserted in the flame. They must be taken not to injure the platinum by allowing it to come in contact with the fused mineral especially if this contains antimony, arsenic, lead, etc. Cheaper forceps, made of steel wire etc., while not so convenient, will also serve reasonably well.

A short length of fairly stout platinum wire to be used in the making of bead tests should be available. A similar length of finer wire for making flame tests is also desirable.

499. Charcoal.—The charcoal employed should not snap and should yield out the ash. The kinds made from basswood, pine or willow are best. It is also conveniently employed in rectangular pieces, say four inches long, or inch wide, and three-quarters of an inch in thickness. The surface must always be perfectly clear before each trial.

500. Glass Tubes.—The glass tubes should be preferably of two grades: a hard glass tubing with about 5 mm. interior diameter to be cut in five inch lengths and used in open tube tests and a soft glass tubing with about 3 mm. interior diameter to be in about six inch lengths, each length yielding two closed tubes.



Blowpipe Flame

501. Blowpipe Flame. The blowpipe flame shown in Fig. 654, consists of three cones: an inner or a core cone, *c*, a second pale violet cone, *b*, and an outer invisible cone, *a*. The cone *c* consists of unburned gas mixed with air from the blowpipe.

There is no combustion in this cone and therefore no heat. The cone *b* is the one in which combustion is taking place. This cone contains carbon monoxide which is a strong reducing agent (see below). Cone *a* is merely a gas envelope composed of the final products of combustion (CO_2 and H_2O). The heat is most intense

near the tip of the cone *b*, and the mineral is held at this point when its fusibility is to be tested.

The point *a*, Fig. 654, is called the oxidizing flame (O.F.), it is characterized by the excess of the oxygen of the air and has hence an oxidizing effect upon the assay. This flame is best produced when the jet of the blowpipe is inserted a very little in the gas flame, it should be entirely non-luminous.

The cone *b* is called the reducing flame (R.F.) it is characterized by the excess of the carbon or hydrocarbons of the gas, which at the high temperature present tend to combine with the oxygen of the mineral brought into it (*a*, *c*), or, in other words, to reduce it. The best reducing flame is produced when the blowpipe is held a little distance from the gas flame, it should retain the yellow color of the latter in its upper edge.

502. Methods of Examination.—The blowpipe investigation of minerals includes their examination, (1) in the forceps, (2) in the closed and the open tubes, (3) on charcoal, or other support, and (4) with the fluxes on the platinum wire.

1. EXAMINATION IN THE FORCEPS

503 Use of the Forceps.—Forceps are employed to hold the fragment of the mineral while a test is made as to fusibility, also when the presence of a volatile ingredient which may give off a very characteristic odor is suspected, for, etc.

The following directions are to be regarded as general ones, and should be modified as the case may require. The fragment of the mineral to be tested should be of such a size that it can be held easily between the jaws of the forceps, and should be of such a shape that it can be heated uniformly. The fragment should be held in the forceps so that the point of the jaws is at the center of the fragment, and the fragment should be held in the forceps so that the point of the jaws is at the center of the fragment, and the fragment should be held in the forceps so that the point of the jaws is at the center of the fragment.

504. Fusibility. All grades of fusibility exist among minerals, from those which fuse in large fragments in the flame of the candle, to those which fuse only on the thin edges, or even in the hottest blowpipe flame, or zinc, and still again there are a considerable number which are scarcely fusible (e.g., corundum).

The exact determination of the temperature of fusion is not easily accomplished (Art 443, p. 312) and for purposes of determination of species is unnecessary. The approximate relative degree of fusibility is fairly fixed by referring the mineral to the following scale suggested by von Kowal.

- | | |
|-------------------------------|----------------|
| 1. Stibnite. | 4. Actinolite. |
| 2. Natrolite or Chalcopyrite. | 5. Epidote. |
| 3. Almandine Garnet. | 6. Biotite. |

505. In connection with the trial of fusibility, the following phenomena may be observed: a coloration of the flame (see Art 506), a swelling of the fragment, a reduction of the mineral, formation of a gaseous or volatile product, and efflorescence, or a spattering of the mass (as in the case of scapolite).

The color of the mineral after ignition is to be noted, and the nature of the fused mass is also to be observed, whether a clear or turbid glass, colorless or of a black, red, blue, or other color, and whether the fused mass is friable or not, and whether it is more or less often colored, etc.

The ignited fragment if nearly or quite fused may be quenched with the cold water, and again ignited if wished, as if it turns blue this indicates the presence of antimony, as with kyanite, topaz, etc. but care should be taken in examining the residue of a mineral. If it becomes powdery, this indicates a compound of impurities.

Also if not too fusible a mineral heated in the forceps be placed upon a strip of moistened turmeric paper, or upon a piece of paper which proves the presence of an alkali, sodium, potassium, or an alkaline earth, calcium, barium, strontium.

506. Flame Coloration. The coloration reported to the observer, however faint, while the mineral held in the forceps is being heated, makes possible the identification of a number of elements.

* Arsenic, antimony and easily reducible metals (as lead and copper) form more or less fusible alloys with platinum.

sulphur (garlic or stuccous odor), and *selenium* (odor of decayed horse-radish) may be recognized.

b. Fusion. In the case of the salts of the alkalis the fused mass is absorbed into the charcoal. This is also true after cooling, of the carbonates and sulphates of barium and strontium. (Art 515.)

c. The Sublimates. By this means the presence of many of the metals may be ascertained. The color of the sublimate both near the assay (N) and at a distance (D) is also when hot and when cool, is to be noted.

The important sublimate are the following:

Substance	Sublimate on Charcoal
Arsenic trioxide (As_2O_3)	White very volatile, distant from the assay, also garlic fumes.
Antimony oxides (Sb_2O_3 and Sb_2O_5), and <i>oxide</i> Zn ¹	White when volatile; forms near the assay. Charcoal is white, and is moistened with nitrate and ignites. O.F. becomes green.
Molybdenum trioxide (MoO_3)	Pale yellow hot, yellow cold. On heat a moment with the F.F. becomes steel-blue. Above copper-plate, green. Moist near the assay.
Lead oxide (PbO)	Dark yellow hot, pale yellow cool. Also from copper-plate dense white, resembling nitrate, & is more so when moisture and a trace of lead.
Bismuth trioxide (Bi_2O_3)	Dark orange-yellow (N), paler on cooling, also bluish white (D). See further, p. 170.
Cadmium oxide (CdO)	Nearly black to reddish brown (N) and orange-yellow (D) when it fuses.

To this above are also to be added the following:

Silver on heating with nitrate is gray (N) to white tinged with red (D). Touched with F.F. gives a white flame, which is often very powdery.

Tellurium on heating with nitrate is white (N) to gray (D). On F.F. volatilizes with green flame.

Mercury on heating with nitrate is faint yellow hot to white cold. Reaction almost green when covered with nitrate solution (F.F.).

Silver with lead, iron and arsenic, sublimate red-brown.

(f) *The Infusible Residue.* This may (1) glow brightly in the F.F., indicating the presence of sodium, strontium, magnesium, or a mixture of any.

(2) It may give an alkaline reaction after ignition, indicating alkalis. (3) It may be friable, showing the presence of water or carbon. (4) It may yield a globule or mass of metal. (Art 513.)

512. Heating on Plaster of Paris Tablets.* In some cases it is preferable to subject gild metals on the surface of a plaster of Paris tablet rather than on charcoal. Such a tablet is easily made by spreading a thin layer of the wet plaster upon a glass plate, the surface of which has been oiled. While the plaster is still in the state of slaking, a thin circular strip measuring about one and a half inches in diameter is cut out. After the plaster has hardened, these can be broken out into the desired tablets. The material thus secured is placed in a small tin, and near one end of the tin a small piece of seaweed or a piece of blotting paper is placed as in the case of charcoal. The same tests are especially marked on the plaster tablet. These are obtained when either oxyhydrogen gas or a flux composed of a mixture of potassium chloride and sulphur is added to the material powder before heating. The important sublimate are listed below.

* A method by which a bit more are formed on sheets of iron has been described by Brady in *Ann. Soc. Min.*, 44, 8, 1921.

Substance	Sublimates on Plaster Tablet
Selenium oxide (SeO_2)	Red to crimson, volatile, giving reddish fumes and characteristic odor.
Iron monoxide FeO , Cassiterite oxide SnO_2	Black, brown, white. Greenish-yellow with brown, both (N) and (D). Non-volatile.
Lead oxide PbO , Bismuth oxide Bi_2O_3	Orange-yellow. Orange-brown with underlying red. Subjected to ammonia fumes it turns into bismuth first orange-yellow then red.
Antimony trisulfide Sb_2S_3 , Antimony oxide Sb_2O_3	Deep blue-black or blue. Orange or red. Disappears when subjected to ammonia fumes.

613 Reduction on Charcoal. In many cases the reducing flame alone suffices on charcoal to separate the metals from the volatile element present, with the result of giving a residue or metal mass. Thus silver is obtained from argente Ag₂S and cerargyrite Ag₂Cl, copper from chalcocite Cu₂S and covellite CuS, etc. The process of reduction is always facilitated by the use of soda or carbonate of soda as a flux, and this is in many cases sufficient to reduce the metal.

The finely pulverized mineral is intimately mixed with two or three times as volume of soda and a small amount of water added to form a paste. This is placed in a cavity in the charcoal and subjected to a strong reducing flame. After such is done as that present sinks into the coal, and, after the process has been continued some time, a considerable globule is often visible on a number of places which can be removed and separated, either hot. If not done, the remainder of the flux, the assay, and the surrounding coal are cut out with a knife and the whole ground up in a mortar with the addition of a little water. The buttons, consisting of a mass away in the middle, are flattened out on a process between two plates of metal. Some metals, as lead, are very easily reduced, as are silver and others as copper and tin, requiring considerable skill and care.

The metals obtained are gold, silver or as a mixture, these may be copper, color red, metallic lustrous, brittle, gold yellow, not soluble in nitric acid, silver white soluble in nitric acid, the solution giving a silver chloride precipitate p. 372. Tin white, harder than silver soluble in nitric acid with precipitation of white powder (oxide) and dark gray (arsenide), soft and fusible. The castings are a test of adulteration, never before serve to identify the metal present.

614. Detection of Sulphur in Sulphates. By means of soda on charcoal the presence of sulphur in the sulphates may be shown, in the following manner. Fuse the powdered mineral with soda and charcoal dust. The mass acting as a strong reducing agent, changes the sulphate to a sulphide with the formation of sodium sulphide. When the fused mass is placed with a drop of water upon a clean silver surface a black or yellow stain of silver sulphide will be formed. A similar reaction would likewise be obtained from a sulphate. The water can however be readily distinguished by running in the open tube or upon charcoal, and not by the formation of SO_2 .

4. TREATMENT ON THE PLATINUM WIRE.

615 Use of the Fluxes. The three common fluxes are borax, salt of phosphorus, and carbonate of soda (p. 361). They are generally used with the platinum wire, (see often on charcoal see above). If the wire is employed it

Fluorine. Heated in the closed tube with potassium hydroxide and powdered glass (see above) the substance fuses, the color of the mass changes to a brownish black, and a white sublimate is deposited on the inner surface of the tube. The sublimate is composed of potassium fluoride and silica. The residue is a black mass, which is soluble in water, and gives a brown solution. This solution is precipitated by the addition of a solution of calcium chloride, and the precipitate is white. The residue is a black mass, which is soluble in water, and gives a brown solution. This solution is precipitated by the addition of a solution of calcium chloride, and the precipitate is white.

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The first of these is the fact that the color of the
 leaves is a good indication of the amount of light
 they are receiving. When a plant is grown in a
 dark place, the leaves are a pale green color.
 When a plant is grown in a bright place, the
 leaves are a dark green color. This is because
 the leaves are able to produce more chlorophyll
 when they are exposed to light. The chlorophyll
 is the substance that gives the leaves their green
 color. It is also the substance that is used by
 the plant to produce food. The leaves of a plant
 are also able to absorb water and minerals from
 the soil. This is done through the roots of the
 plant. The leaves are also able to release oxygen
 into the air. This is done through the stomata
 on the surface of the leaves. The stomata are
 small openings in the leaf that can open and
 close. When the stomata are open, the plant
 can take in carbon dioxide from the air. When
 the stomata are closed, the plant can prevent
 water from evaporating from the leaves. This is
 important for the plant to survive in a dry
 environment. The leaves of a plant are also able
 to respond to changes in light intensity. When
 the light intensity is high, the leaves will
 open their stomata to take in more carbon
 dioxide. When the light intensity is low, the
 leaves will close their stomata to prevent water
 from evaporating. This is a very important
 adaptation for the plant to survive in a dry
 environment. The leaves of a plant are also able
 to respond to changes in temperature. When the
 temperature is high, the leaves will open their
 stomata to release more water vapor. When the
 temperature is low, the leaves will close their
 stomata to prevent water from evaporating. This
 is another important adaptation for the plant to
 survive in a dry environment. The leaves of a
 plant are also able to respond to changes in
 humidity. When the humidity is high, the leaves
 will open their stomata to take in more water
 vapor. When the humidity is low, the leaves will
 close their stomata to prevent water from
 evaporating. This is yet another important
 adaptation for the plant to survive in a dry
 environment. The leaves of a plant are also able
 to respond to changes in the amount of carbon
 dioxide in the air. When the amount of carbon
 dioxide is high, the leaves will open their
 stomata to take in more carbon dioxide. When
 the amount of carbon dioxide is low, the leaves
 will close their stomata to prevent water from
 evaporating. This is the final important
 adaptation for the plant to survive in a dry
 environment. The leaves of a plant are able to
 respond to all of these changes in their
 environment. This is why the leaves of a plant
 are so important for the plant's survival.

PART IV. ORIGIN, MODE OF OCCURRENCE AND ASSOCIATION OF MINERALS*

[illegible]

621 Chief Modes of Mineral Origin. 1. From Fusion. The greater part of the minerals that occur in the crust of the earth have been formed by solution of a magma, fused and cooled, that is, by one of the crystallization, reagents of igneous rocks.

Abstract. Many number fields have been defined by explicit equations. This is done over the group of algebraic numbers. However, it is not clear how to define the group of algebraic numbers. In this paper, we define the group of algebraic numbers as the group of algebraic numbers which are roots of unity. This definition is equivalent to the usual definition of algebraic numbers. We then show that the group of algebraic numbers is a free abelian group of rank ∞ . This result is a generalization of the result of Artin and Schreier that the group of algebraic numbers is a free abelian group of rank ∞ .

The following are some of the minerals found in the soil:

- Calcium
- Magnesium
- Potassium
- Sulfur
- Phosphorus
- Nitrogen

is a very attenuated one.

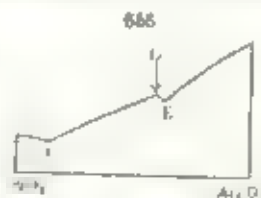
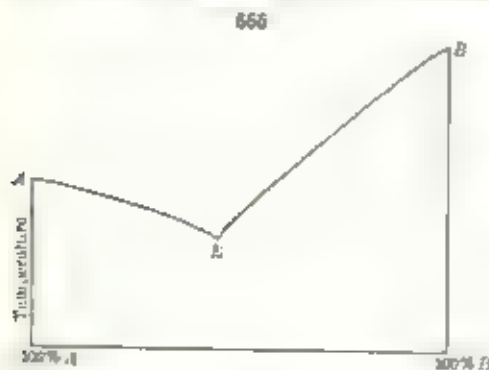
522 The Formation of Minerals from Fusion—An igneous rock has its origin in a process of fusion, or the melting of a solid material. An igneous rock has been called a "magma" because it is a "heavy" or "gross" material.

$$M_{\text{eff}} = \frac{M}{1 + \frac{M}{M_0}} \quad (25)$$

which the various elements present are more or less free to circulate and under the proper conditions to unite to form mineral molecules. The composition of the magma will determine in large part the character of the minerals that compose the resulting rock. By the study of thousands of analyses of igneous rocks it is shown that the following constitute about 99 per cent of the elements present: oxygen, silicon, aluminum, iron, magnesium, calcium, sodium, and potassium. These elements occur in varying proportions in igneous magmas but the constituent minerals of igneous rocks are composed essentially of them. The conditions under which the various minerals are formed are complex. They crystallize out from the cooling magma in general in the order of their solubilities. Although this order is fairly definite, yet the variation of the chemical composition of the magma will vary the degree of solubility of the various minerals, consequently they vary the order of their crystallization. The fluidity of the magma and the temperature at which various minerals will crystallize are influenced greatly by the common presence in a magma of small amounts of substances that are known as mineralizers. These are usually water vapor, carbon dioxide, fluorine, boron, and sulfur and chlorine. To some extent these enter into the composition of various rock-making minerals, but the part they play in the formation of igneous rocks is more a physical one. It has for instance been shown experimentally that such common rock mineralizers as carbon dioxide and quartz can cause a rock formed from a dry fusion, as a rule, into amorphous glasses will result in such a case. It is not in the presence of water vapor that the temperature of crystallization is sufficiently lowered and the fluidity of the magma increased so

as to permit the ready growth of crystals of these minerals.

When two substances (*A* and *B*) are mixed together in various proportions and then fused, the temperatures of solidification of the mixtures are in general



lower than the corresponding temperatures of either of the pure substances. In Fig. 655 the temperatures of the mixtures in *A* and *B* are purely theoretical and the temperature of solidification is indicated. The point *E* represents the point of maximum fluidity of the mixture. Such a point is known as the *eutectic point* of the mixture of *A* and *B* that corresponds to it is called the *eutectic mixture*. This is the case of two components, particularly the effect of a solvent on temperature of the compound. In presence of the liquid mixture of *A* and *B* form for some certain degrees a definite compound A_2B , then the curves will show two eutectic points, one between *A* and A_2B , and the other between

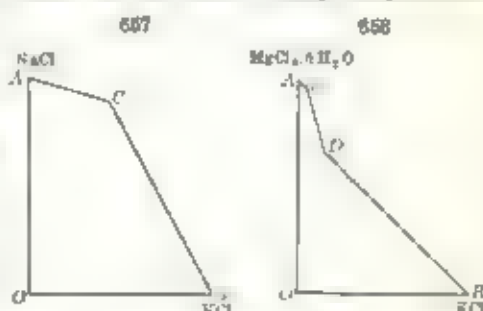
A, B, and C Such a condition is represented in Fig. 656, which gives the fusing curves for mixtures of SiO_2 and Al_2O_3 . The point *c* represents the mineral sillimanite, Al_2SiO_5 , and the points *E* the eutectic points on either side of it. If there are two or more possible different molecular combinations of *A* and *B*, the curves become increasing in complexity. It can be readily seen that if in addition the fused mass, i.e., the rock magma, contains, as is usually the case, several different chemical components, the problems involved in the crystallization of the constituent minerals of the rocks are enormously different of solution.

There has been in recent years, however, a great amount of experimental investigation concerning the behavior of various systems of oxides under conditions of high temperature and pressure. In this way our knowledge of the physical and chemical processes involved in the crystallization of minerals from rock magmas is being greatly extended.*

523. The Formation of Minerals from Solution. 1) *By the Evaporation of Saline Waters*—Ocean waters and the waters of salt lakes contain various salts in solution, when such waters become concentrated through evaporation, certain minerals are deposited.

The saline content of sea-water is composed of the following constituents: NaCl , about 78 per cent; KCl , 2 per cent; MgCl_2 , 9 per cent; MgSO_4 , 6 per cent; CaSO_4 , 4 per cent. When such waters are evaporated, the above salts, or certain combinations, such as carnallite, $\text{KCl} \cdot \text{MgCl} \cdot 6\text{H}_2\text{O}$, crystallize from the solution in the order of their solubility. In general, the normal

order of crystallization is as follows: carbonates of lime and magnesium, calcium sulphate, sodium chloride, magnesium chloride and sulphate, potassium chloride, etc. The factors of concentration, temperature, and proportions of the various constituents in the solution can greatly be character of the minerals formed, their relative amounts, the order of the deposition, etc. For instance, in the case of NaCl and KCl , the amount of each that can be dissolved in a given solution is controlled by the amount of the other salt also present. In Fig. 657 the distance $O-A$ represents the amount of NaCl that can be dissolved in a given amount of water at a given temperature, and $O-B$ represents the amount of KCl that can be dissolved in the same way. The line AB gives the varying proportions of the two salts that together form a saturated solution. The point *c* represents the maximum amount of the two salts that may be dissolved. The line of saturation for mixtures of two salts in a solution will be further explained if they may form one or more double salts. Such a case



* The results of these investigations are to be found in many papers in the various journals. They are given, however, in the following books:

Chamber, *Physical Chemistry*, 1916.
 Hildebrand and Langer, *Chemistry*, 1927.
 Fieser, *Physical Chemistry*, 1928, p. 29.

For an explanation of the physical-chemical processes see an overbook on physical chemistry, and especially, *The Phase Rule and its Applications*, by F. H. 1927.

is illustrated in Fig. 105. The two salts are those for $MgCl_2 \cdot 6H_2O$ and KCl . Together these make up the mineral $MgCl_2 \cdot 2KCl \cdot 10H_2O$. From D represent the combination of salts not for both carnallite and sylvite, but the for carnallite and together. The mineral is growing the crystals of salt, starting from bodies of salt water and not extremely salted. H. H. and his students have experimentally and in the famous salt beds of Prussia.

Another important type of salt deposit occurs when the waters of lakes have dried up, leaving a salt crust. These waters contain a large amount of salt, and when the water has evaporated, the salt remains in the water. The salt is then deposited in the form of a crust, and the water is then evaporated. The salt is then deposited in the form of a crust, and the water is then evaporated. The salt is then deposited in the form of a crust, and the water is then evaporated.

(2) by Evaporation from Ground Water. The rocks of the earth's crust have many openings with a high degree of permeability. These openings vary in size from microscopic pores to large cavities. They may be irregular in shape, and they may be filled with water. The water in these openings is under pressure, and it may be forced out of the rock by the action of the water. The water is then evaporated, and the salt is deposited in the form of a crust. The salt is then deposited in the form of a crust, and the water is then evaporated. The salt is then deposited in the form of a crust, and the water is then evaporated.

but that there are openings left along its external line. These openings, termed stoma are left between the rigidized members. These stoma were used for easy expansion and contraction. But the stoma is not a very well known feature of the cell membrane. I must be responsible for this. I am sure that to every body, present or absent, a cell is a unit and that the stoma is a very important feature of the cell membrane.

[illegible]

It is important to remember that the electrolyte is usually a salt, and the anion is usually a halide or sulfate. The cation is usually a metal ion, and the anion is usually a non-metal ion. The electrolyte is usually a salt, and the anion is usually a halide or sulfate. The cation is usually a metal ion, and the anion is usually a non-metal ion.

are usually monomeric calcium salts.

§24. Occurrence and Association of Minerals

524. Occurrence and Association of Minerals. The mineral assemblage in the rocks is primarily composed of quartz, feldspar, and mica. The quartz is typically found in the form of small, irregular grains, while the feldspar is more abundant and often forms larger, more regular grains. Mica is present in smaller quantities, often as thin, platy grains. The association of these minerals is characteristic of a felsic igneous rock, such as granite or diorite. The texture of the rock is generally coarse-grained, with the minerals interlocking to form a crystalline structure. The presence of these minerals suggests a high-silica, high-alumina composition, typical of rocks derived from a felsic magma. The distribution of the minerals is relatively uniform throughout the sample, with no significant zoning or segregation observed. The overall mineralogy is consistent with a rock of intermediate to felsic composition, possibly a diorite or a granite.

[illegible]

* *Diels of Geochemistry*, p. 32, 1910.

The following paragraphs describe briefly the more important modes of mineral occurrence and the more characteristic types of mineral association.

525. Occurrence in Rocks. — Although many minerals are found as rock constituents those which can be termed common and characteristic rock-making minerals are comparatively few in number. The following are included in such species, although some of these occur only in rare rock types: quartz, the feldspars, nepheline, sodalite, leucite, the micas, the pyroxenes, the amphiboles, hornblende, kyanite, the chlorites, serpentinite, talc, calcite, and dolomite. In addition to the more important and common rock-making minerals there is a group of minerals which are characteristic only found as rock constituents but in a minor way. They occur usually only as small and scattered crystals in the rock and seldom become one of its prime constituents. These minerals are known as accessory or *accessory minerals*. A great many different minerals may at times occur in a single rock exhibiting, but the following may be taken as those that characteristically occur in this way. The most common in general epidote, allanite, kyanite, apophyllite, titanite, zircon. The following are of rarer occurrence: rutile, ilmenite, zirconolite, allanite, titanite, In addition, the rare minerals magnetite, hematite, ilmenite, and pyrite, also may occur in accessory rock minerals.

526. Igneous Rocks. Igneous rocks, as the name indicates, are those which have been formed by the cooling and consequent solidification of a molten and fluid mass of rock material, which is known as a magma (see Art 522). In most igneous rocks a more or less definite order of crystallization of the minerals constituents can be determined. In general the more basic minerals or those which contain the smaller amounts of silica which is the acid element in igneous rocks are found to crystallize first and the more acid minerals last. Among the commonest rock-forming minerals the following would be the usual order of crystallization: olivine, pyroxene, hornblende, then the feldspar group, and finally the quartz. Next the pyroxene and feldspar, then the amphiboles and the chlorites.

The type of mineral to be found in any igneous rock will depend chiefly upon the chemical composition of the magma from which it was formed. A characteristic feature of a high percentage of silica in the magma is that the resulting rock will contain the feldspar and quartz in an abundance of free quartz. It would usually be light in color. If of the silica a low percentage, a low percentage of silica, or in other words was basic in character the resulting rock would contain the feldspar and quartz in small amounts and would be dark in color. It would also in general be dark in color.

In addition to the wide variation in chemical and mineral composition shown by igneous rocks there is also a variation in their physical structure. This is dependent upon the mode of origin of the rock. A rock has been formed from a magma which has cooled slowly and the crystals of the minerals have cooled very slowly and the resulting product is a fine-grained crystallization and smooth even. In other cases cooling has been rapid and the minerals have had the opportunity to grow to considerable size. A rock having such a coarse-grained origin is therefore, a coarse-grained rock and the crystals are large and go to form the rock can often be seen with the unaided eye. Such rocks are called *coarse-grained rocks*. They are also termed *phanitic*. They are also termed *granitic* rocks or *phanites*.

minerals of which cannot be determined by inspection. It would include
 basalt, dolerite, etc.

521 Igneous Rocks. Some of the rocks which are commonly
 met in the crust of the earth are of igneous origin. They are
 formed by the cooling and solidification of a molten mass of
 magma. The process of their formation is called *igneous*. The
 rocks are divided into three classes: *intrusive*, *extrusive*, and
volcanic. Intrusive rocks are those which have solidified
 beneath the surface of the earth. Extrusive rocks are those
 which have solidified on the surface of the earth. Volcanic
 rocks are those which have been formed by the eruption of
 lava from a volcano. The rocks are also divided into *acidic*,
intermediate, and *basic*. Acidic rocks are those which
 contain a high percentage of silica. Intermediate rocks
 contain a moderate percentage of silica. Basic rocks contain
 a low percentage of silica. The rocks are also divided into
granitic, *dioritic*, and *basaltic*. Granitic rocks are those
 which are composed of quartz, feldspar, and mica. Dioritic
 rocks are those which are composed of feldspar and mica.
 Basaltic rocks are those which are composed of feldspar and
 pyroxene. The rocks are also divided into *igneous* and
metamorphic. Metamorphic rocks are those which have
 been formed by the action of heat and pressure on igneous
 rocks. The rocks are also divided into *igneous* and
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 been formed by the action of heat and pressure on igneous
 rocks.

522 Sedimentary Rocks. Sedimentary rocks are those which
 are formed by the deposition of material from a liquid or
 gaseous medium. They are formed by the action of water,
 wind, or ice. The rocks are divided into *clastic*, *chemical*,
 and *biological*. Clastic rocks are those which are formed
 by the deposition of fragments of other rocks. Chemical
 rocks are those which are formed by the precipitation of
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chemical change they are precipitated upon its floor, also in horizontal layers. These *sediments*, *forms of sediments* are ultimately consolidated into the masses known as *sedimentary rocks*.

Sedimentary rocks are therefore characterized by a parallel arrangement of their constituent particles into layers and beds which are to be distinguished from each other by differences in thickness, size of grains and often in color. It is to be noted, further, that sedimentary rocks in general are composed of an aggregate of individual mineral particles (sand, silt, clay, etc.) of which stands out in a way by itself and does not have that intimate interlocking relation with the surrounding particles which is to be seen in the materials of an igneous rock. In all the coarser-grained sedimentary rocks there is some material which, acting as a cement, surrounds the individual mineral particles and binds them together. This cement is usually calcareous, carbonaceous or of iron oxide. The chief minerals to be found in sedimentary rocks are quartz and calcareous cement or dolomite. These give rise to the two chief types of sedimentary rocks, the sandstones and the limestones. A full description of these rocks follows.

[illegible]

2. Sandstones are very fine-grained sandstones which have been formed by erosion and deposition of sand and silt. They have formed a characteristic pattern of erosion. Their color is commonly some shade of gray or green, but may be white, yellow, green, or black. They are composed of the grains of quartz, feldspar, and other minerals, and are cemented together by the growth of a mineral cement, usually calcareous. By the action of water and air, and the increase in the size of grains, they grade into the sandstones.

3. Intermediate The intermediate or middle rocks composed usually chiefly of quartz and feldspar, and in some cases a little mica, and are called "The middle zone" in the strata. They are in some cases extracted from the sea water by the agency of the tide, and then appear as a mass which is not so hard as the rock. These rocks are usually fine in texture and in structure, and are quite dense. Some fine

stones are quite pure calcite, while others contain claylike materials and various oxides as impurities. The color of a limestone is usually gray, although it may be white, yellow, brown, or almost black. *Travertine* or *travertine* is a variety which occurs in aggregates of small spherical concretions. *Chalk* is a very fine-grained friable mass, or composed of small, of minute sea shells, known as forams. *Travertine* is a deposit of pure or carbonate formed by springs. A fine example exists in the deposits formed by the Mammoth Hot Springs, Yellowstone Park. *Marmor* is a coarse-grained crystal composed of a carbonate mixed with clay in various amounts.

4. *Other Sedimentary Formations.* Included in the sedimentary rocks are all of those occurring in large masses and various minerals that have been precipitated from water. See also Art. 523. *Rock salt* occurs in great quantities as a part of the sedimentary series and is usually beneath glacial or horizon. Its beds vary in thickness from one to many feet. *Gypsum* also occurs in many places and is found in thick beds. It occurs in nodules and layers, and is especially associated with lignites and shales. *Lithology*, though less frequent in its occurrence is found under certain conditions. Some of the other rocks that occur in these beds. *Geyserite* is composed from hot springs either by the evaporation of the water or by the action of a gas which is expelled from the water in which they rise. *Travertine* is earthy and fine-grained rock-like material formed from the sides of some of the hot springs that are in water. At times occurs in beds of considerable extent. The rocks are usually brown and siliceous may occur in sedimentary beds or further under or descriptions of the individual species. In certain regions, beds of impure calcite in places, known as *phosphatic* or *phosphatic rock*, occur see under apatite, p. 514.

528. **Metamorphic Rocks.** Metamorphic rocks are rocks which have undergone some chemical or physical change subsequent to their original formation. This change has been brought about by means of heat, temperature and pressure, or by the action of water and other chemical agents. The changes involve the constitution of new minerals, the change of structure of chemical constituents and a physical change, some of the particles conform to the existing pressure. The original rock from which a metamorphic rock has been derived may be either igneous or sedimentary. As these rocks become involved in movements of the earth's crust they are subjected to extreme pressures accompanied usually by high temperatures. The result will be that they will be changed into new rocks and others may be changed into the new conditions. Although many minerals that were constituents of the original rock may still exist in the new rock, the composition of the rock will be changed by the action of the new conditions. During the process some of the minerals present in the metamorphic rocks are transformed into new minerals. Some of the new minerals, however, are formed. The physical structure of the rock will also undergo change during the process. Because of the pressure to which the rock is subjected the mineral particles will be more or less broken and the new minerals arranged in parallel layers. The new minerals are arranged to give by the parallel arrangement of the minerals the new structure of the metamorphic rock. Because of this a metamorphic rock will be different from an igneous rock. Further in the great majority of cases a metamorphic rock has a crystalline structure which distinguishes it from a sedimentary rock.

cially of quartz, feldspar and mica. The quartz and feldspar crystals may be several feet in length and the mica plates are at times more than a foot across. In addition to the coarseness of the crystals and the size of the veins, these veins possess other peculiar features. In the case of pegmatite veins of the type here under consideration, the veins, in order that they may be in the granitic rock mass, and their crystals may grow in regular symmetrical forms. These veins will also at times show a tabular or lamellar structure, in which the different minerals occur in distinct layers which lie parallel to the walls of the veins. Their formation is also characterized by a regularity in their growth through the mass, so that a single vein is composed wholly of feldspar and again the other may be pure quartz. Frequently, along the outer portions of the veins, as the openings will be formed by the walls of the crystals, the different minerals proper to these veins may be found in a somewhat different order from the pegmatite veins from the granitic rock with which they are associated.

An extended and detailed discussion of the theory of the origin of pegmatite veins can be given here. It may be briefly summarized as follows. The veins are formed during the last stage of the cooling of a granite mass and are formed in the granitic rock. As the granitic magma cools and shows signs of becoming solid, it is still in a plastic condition and the pressure due to the weight of the rock mass may be so great that the interior of the mass of the granite may be broken up into fragments that may exist in the surrounding rocks. If, during the process of breaking up the granite rock due to the weight of the surrounding rock mass, a pegmatite vein is formed, it is a pegmatite vein. As the granitic magma cools and the weight of the magma is frequently so great that the magma of the granitic rock may be broken up into fragments and water may be expelled from the magma, consequently it becomes a magma and the magma may be so concentrated and raised. This may be the cause for the peculiar formation of veins in pegmatite veins which differ from the ordinary granitic veins.

The origin of the pegmatite veins may be explained in a very general way. It is when these minerals which form the mass of the magma are so concentrated and when the magma is so concentrated as to be able to be broken up into fragments and water may be expelled from the magma, consequently it becomes a magma and the magma may be so concentrated and raised. This may be the cause for the peculiar formation of veins in pegmatite veins which differ from the ordinary granitic veins. The presence of the minerals which form the mass of the magma is so concentrated and when the magma is so concentrated as to be able to be broken up into fragments and water may be expelled from the magma, consequently it becomes a magma and the magma may be so concentrated and raised. This may be the cause for the peculiar formation of veins in pegmatite veins which differ from the ordinary granitic veins.

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served. These being of no particular commercial value are called *gangue minerals*; gangue is from *gang* a vein. They include the following: quartz, SiO_2 , calcite, CaCO_3 , dolomite, $\text{CaMg}(\text{CO}_3)_2$, siderite, FeCO_3 , barite, BaSO_4 , fluorite, CaF_2 , chlorite, $\text{Fe}(\text{OH})_2$, MnCO_3 , etc.

Ludgren* has classified *ore minerals* according to the range of temperature that probably prevailed during their formation and since in general temperature will increase with depth, also roughly according to the depth below the earth's surface at which deposition took place. The low temperature minerals, 50–150° C., include pyrite, marcasite, sphalerite and chalcocite as ore minerals, and siderite, quartz, calcite, galena, fluorite, azurite, etc., rarely as gangue minerals. The deposited intermediate temperature, 150–300° C., show gold, galena, sphalerite, pyrite, chalcocite, barite, arsenopyrite, stibnite, cerussite, magnetite, etc., as ore minerals, whereas the principal gangue minerals are quartz, calcite, dolomite, siderite and barite. The high temperature deposits, 300–500° C., contain gold, gold tellurides, molybdenite, cassiterite, wolframite, magnetite, ilmenite, various oxides, garnet, topaz, apatite, etc.

While not particularly few positive statements concerning the associations of vein minerals can be made, the following points are of interest:

1. *Gold-bearing Quartz Veins*.—Native gold is most commonly found in quartz veins. It may occur disseminated in the quartz, either in nests or in finely disseminated particles, or it may occur in contact with certain sulphides in a vein. The most common sulphides found in such instances are pyrite, chalcocite and arsenopyrite.

2. *Iron and Silver-bearing Copper Veins*.—The gold and silver content of these veins is associated with the various copper sulphides. Frequently the amount of the precious metals is quite small. The chief minerals are chalcocite, tetrahedrite, bornite, chalcocite, pyrite and various other silver minerals.

3. *Silver-bearing Lead Veins*.—Silver and lead minerals are very commonly associated with each other. These veins commonly contain galena, argentite, cerussite, sphalerite, pyrite, calcite, dolomite, fluorite, chlorite, etc.

4. *Lead-iron Veins*.—Lead and zinc minerals often occur together particularly in deposits that lie in igneous rocks. Chief minerals of such deposits are galena, sphalerite, cerussite, chalcocite, arsenopyrite, chalcocite, cerussite, calcite, dolomite.

5. *Copper-iron Veins*.—Copper and iron sulphides are quite commonly associated with each other in primary veins, such veins being pyrite, chalcocite, arsenopyrite, bornite, tetrahedrite, chalcocite, etc.

532. Primary and Secondary Vein Minerals. Secondary Enrichment.

It is very common to find veins that contain minerals belonging to the original vein deposit while others have been formed subsequently. These two classes of minerals are known respectively as *Primary and Secondary Minerals*. The primary vein minerals are those which were originally deposited by the ascending waters in the vein fissure. The primary metal-bearing veins are comparatively few in number, the more important being pyrite, chalcocite, galena and sphalerite. The secondary vein minerals have been formed from the primary minerals by some subsequent chemical

$\text{Cu}(\text{OH})_2 \cdot \text{CO}_3$, *azurite*, $\text{Cu}(\text{Cu}(\text{OH})_2(\text{CO}_3)_2)$, *chrysocolla*, $(\text{CuSiO}_3)_2 \cdot 2\text{H}_2\text{O}$, *chalcocite*, Cu_2S , $5\text{H}_2\text{O}$.

3. *Lead Minerals*—The one primary lead mineral is *galena*, PbS . The secondary minerals of lead are all oxidized compounds and include the following: *cerussite*, PbCO_3 , *anglesite*, PbSO_4 , *pyromorphite*, $3\text{PbO} \cdot \text{PbCl}_2 \cdot \text{PO}_4$, *wulfenite*, PbMoO_4 .

4. *Zinc Minerals*—*Sphalerite*, ZnS , is the only common primary zinc mineral. The chief secondary minerals are *smithsonite*, ZnCO_3 , and *silicozincite*, $\text{Zn}_2(\text{O},\text{SiO}_3)_2$.

5. *Silver Minerals*—Probably most of the deposits of minerals of silver are primary in their origin. The following, however, are usually secondary, although native silver at times appears primary: *native silver*, Ag , *cerargyrite*, AgCl , *embolite*, $\text{Ag}(\text{Cl},\text{Br})$, etc.

PART V. DESCRIPTIVE MINERALOGY

533. Scope of Descriptive Mineralogy. — It is the province of Descriptive Mineralogy to describe each mineral species as regards 1. form and structure, 2. physical characters, 3. chemical composition, 4. its origin, its localities, its uses, and its relations to geological history, and association with other species, also its connection with the various laws which may be used to distinguish it from other species. Further, it should class various mineral species into more or less natural groups according to some characters regarded as most essential. Other points which may or may not be included are the investigation of the mechanism of formation, the changes that they undergo in nature and the results of such alterations, also the methods by which to separate them, but may be made in the laboratory, finally the use of minerals as ores, or ornament and in the arts.

534. Scheme of Classification. — The method of classification adopted in this work and the one which can alone be said to be thoroughly scientific is that which brings together all compounds together and compounds closely related with minor changes. Several systems of groups are being called in to regulate relations existing between them in chemical composition, crystalline form and other physical properties.

Under the basis of composition, we might distinguish chemical classes, beginning with the Native Elements. These are enumerated on the following page. To form our first section, different gradations might also be made in their physical characters. Under the modern species the series are arranged, as far as possible, in ascending groups, ascending ones which have a greater amount of oxygen, and descending ones which have less. (See Art. 483.) It is necessary to keep in view the development of the scheme of classification, and the necessity of the successive sections under any one of the divisions, to make the principles of classification clear. A few remarks, only, are added to make a sketch of it.

Under the basis of composition the classification is as follows. First, the Oxygen series, quartz, etc., etc., and Second, the Oxygen of base minerals, to be kept apart, as usually done, from the metaborates, tungsten. Third, the Oxygen of the metal oxides, copper, iron, many magnesian, etc., etc. The third section is then subdivided into binary, ternary and various species. Further, the term tellurides is further divided. First comes $\text{R}_2\text{O} \cdot \text{Te}$, sesquioxide, $\text{RO} \cdot \text{Te}$, then the *te* oxides $\text{RO} \cdot \text{RO} \cdot \text{Te}$, etc., etc., $\text{RO}_2 \cdot \text{Te}$. Under each of these heads come binary and various species arranged so far as possible in isomorphous groups. Thus we have the Hematite group, the Rutile group, etc.

In regard to the various classes of salts it may be stated that, in general,

they are separated from the igneous and basic and hypobasic sections, the special subdivisions are different, however, in the different cases.

For an explanation of the subdivisions used in the descriptive species, see p. 5.

SCHEME OF CLASSIFICATION

- I. NATIVE ELEMENTS.
- II. SULPHIDES, SELENIDES, TELLURIDES, ARSENIDES, ANTIMONIDES.
- III. Sulpho-salts: SULPHARSENITES, SULPHANTIMONITES, SULPHOBISMUTHITES.
- IV. Haloids: CHLORIDES, BROMIDES, IODIDES; FLUORIDES.
- V. OXIDES.
- VI. Oxygen Salts.
 1. CARBONATES.
 2. SILICATES, TITANATES.
 3. NIOBATES, TANTALATES.
 4. PHOSPHATES, ARSENATES, VANADATES, ANTIMONATES; NITRATES.
 5. BORATES, URANATES.
 6. SULPHATES, CHROMATES, TELLURATES.
 7. TUNGSTATES, MOLYBDATES.
- VII. Salts of Organic Acids: OXALATES, MELLATES, ETC.
- VIII. HYDROCARBON COMPOUNDS.

I. NATIVE ELEMENTS

THE NATIVE ELEMENTS are divided into the two distinct sections of the Metals and Non-metals, and these are collected in a separate class of the system as the first subdivision, in view of their peculiar physical characters and their different uses as minerals, seen generally in Art. 465.

The only non-metals present in our list are carbon, sulphur and selenium, the first of these in its allotropic forms, as closely related to the second as to the first.

The metals are divided into a distinct group by themselves, since all crystallize in the rhombohedral system, and are distinguished from the non-metals by a few other characters differing from the non-metals, as follows, as shown in the following list:

Iron, $\sigma = 91^{\circ} 3'$
 Antimony, $\sigma = 92^{\circ} 53'$

Arsenic, $\sigma' = 94^{\circ} 54'$
 Bismuth, $\sigma = 92^{\circ} 26'$

An artificial metal, osmium, is known, with baric-like habit and rhombohedral crystallization, $\sigma = 90^{\circ}$. Zirconium, tin, and lead, which crystallize, $\sigma' = 91^{\circ} 48'$, and are easily distinguished from the true metals. Metallic platinum has been discovered, $\sigma = 90^{\circ}$.

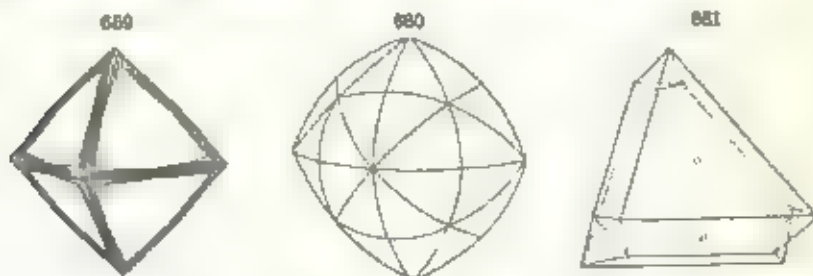
Among the metals, the section of the noble metals is prominent, including gold, silver, copper, mercury, and platinum.

Another related section is that of the metals, platinum, iridium,

palladium and iron. An allotropic form of palladium and also iridosmine (IrOs) are both rhombohedral.

DIAMOND.

Isometric. The development of certain crystals as well as etching tests have suggested tetrahedral symmetry but X-ray study (cf p. 40) shows that the atomic structure conforms to normal symmetry. Commonly showing octahedral, hexoctahedral, and other forms, faces frequently rounded or striated and with triangular depressions on octah. Twins common with tw. pl. $\{111\}$ and often flattened parallel to o . Crystals often distorted. In spherical forms massive.



Cleavage $\{111\}$ highly perfect. Fracture conchoidal. Brittle. $H = 10$. $G = 3.516-3.525$ crystals. Luster adamantine to greasy. Color whitish to colorless, occasionally various pale shades of yellow, red, orange, green, blue, brown (rare), deeply colored sometimes black. Usually transparent, also translucent opaque. Refractive and dispersive power high, index $n = 2.4195$ (See Art. 334). Usually isotropic but sometimes shows anomalous birefringence. Shows at times brilliant phosphorescence when rubbed or exposed to the electric discharge in a vacuum tube, to ultra-violet light, etc.

Var. 1. Ordinary. In crystals usually with rounded faces and varying from those which are colorless and free from flaws, near colorless through many faint shades of color, yellow being the most common, often full of flaws and hence of value only for cutting purposes.

2. Bort, Bort or Bort. Crystals large with rough exterior and rounded or rounded crystals. Also known as diamonds of inferior quality or even rough stones. Carbonaceous or carbon. Black, black, black. Masses of crystals, granular to coarse, without cleavage. Color black or grayish black. Opaque. Shattered chips from natural brand.

Comp. Pure carbon, the various carbonates yellow on contact on a slight ash.

Pyrr. etc. Unaffected by heat except at very high temperatures when it burns in atmosphere. Burns in carbon dioxide. It is not affected by the atmosphere at 1000°C. No action from acids or alkalis.

Diff. Distinguished by its quartz crystal. Its extreme hardness and brilliant natural luster. The latter character and high specific gravity are also characteristic of diamond. It is optically isotropic, transparent to X-rays, which distinguishes it from glass and talc.

Artificial. Various ways have been described in which synthetic diamonds have been formed artificially. It has been shown, however, that at least in some cases, the supposed diamond crystals do not possess the requisite refractive index or structure.

Obs. The accidental occurrence of this mineral in a variety of granites and in many other rocks is well known. It is often found in the form of small, irregular, colorless, transparent crystals, which are sometimes aggregated in clusters. The crystals are usually small, but occasionally they may reach a size of 1/2 inch or more. They are often found in the form of small, irregular, colorless, transparent crystals, which are sometimes aggregated in clusters.

It has been found in a variety of rocks, including granite, gneiss, and schist. It is also found in the form of small, irregular, colorless, transparent crystals, which are sometimes aggregated in clusters. The crystals are usually small, but occasionally they may reach a size of 1/2 inch or more. They are often found in the form of small, irregular, colorless, transparent crystals, which are sometimes aggregated in clusters. The crystals are usually small, but occasionally they may reach a size of 1/2 inch or more. They are often found in the form of small, irregular, colorless, transparent crystals, which are sometimes aggregated in clusters.

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found in 1921. The mineral is also found in the form of small, irregular, colorless, transparent crystals, which are sometimes aggregated in clusters. The crystals are usually small, but occasionally they may reach a size of 1/2 inch or more. They are often found in the form of small, irregular, colorless, transparent crystals, which are sometimes aggregated in clusters. The crystals are usually small, but occasionally they may reach a size of 1/2 inch or more. They are often found in the form of small, irregular, colorless, transparent crystals, which are sometimes aggregated in clusters.

House, near Goose Lake, New York. Found in metamorphosed Carboniferous rocks near Proctorville, Ohio. Found also in the rocks of the Allegheny and elsewhere. A small amount of the mineral is also found in the rocks of the metamorphic zone of igneous intrusions on coal fields.

Use. Its chief uses are in making cements and other refractory products. In cements it is used as a filler, and in the manufacture of other refractory materials.

The mineral is a white to light gray color, and is found in the rocks of the metamorphic zone of igneous intrusions on coal fields.

Almost pure. A black, opaque material composed chiefly of carbon and sulphur from the volcanic rocks of Montserrat, I. C.

SULPHUR.

Orthorhombic. Axes $a : b : c = 0.31 : 1 : 1.0034$.

Crystals commonly in the form of thin, white, tabular, $\{001\}$.

See also fig. 97, p. 64. Crystals are sometimes split into halves, etc.

They suggest such a symmetry, but

by X-ray indicates a different

symmetry for the atomic structure.

It is a rhombic. Also massive in

thin shapes, sometimes

irregular in powder.

Fracture conchoidal to

imperfect. Fracture conchoidal to

imperfect. Rather brittle to

imperfect. $H = 1.5-2.5$, $G = 2.05$.

2.4. Luster resinous. Color sulphur-

yellow, gray and ochre-yellow,

yellowish brown, greenish-yellow to

yellowish brown, greenish-yellow to

yellowish brown, greenish-yellow to

yellowish brown, greenish-yellow to

yellowish brown, greenish-yellow to

yellowish brown, greenish-yellow to

yellowish brown, greenish-yellow to

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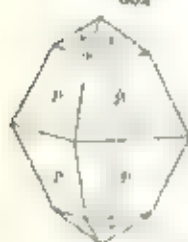
yellowish brown, greenish-yellow to

yellowish brown, greenish-yellow to

yellowish brown, greenish-yellow to

662

663



Sulphur Crystals

Lowish gray. Streak white. Transparent to translucent. A non-conductor

of electricity. By the negative electrode. A poor conductor of heat.

Optical. $n_g = 1.98$, $n_x = 1.97$, $n_y = 1.96$. $\alpha = 0.0001$, $\beta = 0.0001$, $\gamma = 0.0001$.

Dispersion $n_g - n_x = 0.01$, $n_x - n_y = 0.01$, $n_y - n_z = 0.01$.

Comp. Pure sulphur. Often contaminated with iron, copper, and

other impurities.

Sulphur is a non-metallic element. It is found in the free state in the

Volcanic rocks of the Hawaiian Islands. It is also found in the

sedimentary rocks of the Mississippi Valley. It is also found in the

igneous rocks of the Andes. It is also found in the

metamorphic rocks of the Alps. It is also found in the

metamorphic rocks of the Himalayas. It is also found in the

metamorphic rocks of the Pyrenees. It is also found in the

metamorphic rocks of the Apennines. It is also found in the

metamorphic rocks of the Carpathians. It is also found in the

metamorphic rocks of the Balkans. It is also found in the

metamorphic rocks of the Caucasus. It is also found in the

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metamorphic rocks of the Caucasus. It is also found in the

metamorphic rocks of the Caucasus. It is also found in the

metamorphic rocks of the Caucasus. It is also found in the

metamorphic rocks of the Caucasus. It is also found in the

the separation of sulphur. The decomposition of metallic sulphides thus produces sulphur also.

Sulphur is most commonly found in the tertiary sedimentary rocks and is most frequently associated with bitumen, asphalt, and other hydrocarbons. It is also associated with iron, copper, and lead. It is found in the form of native sulphur, as well as in the form of various sulphides.

The most important sources of sulphur are naturally occurring, because of their abundance in the earth's crust. The most important sources are the volcanic regions of Japan, Hawaii, Mexico, and America. The most important sources are the volcanic regions of Japan, Hawaii, Mexico, and America.

The most important sources of sulphur are naturally occurring, because of their abundance in the earth's crust. The most important sources are the volcanic regions of Japan, Hawaii, Mexico, and America. The most important sources are the volcanic regions of Japan, Hawaii, Mexico, and America.

Use. In the manufacture of sulphuric acid, which is used in the manufacture of many other chemicals. Sulphur is also used in the manufacture of gunpowder, matches, and other explosives.

Seleniophur Volcanic. Seleniophur is a native element found in the volcanic regions of Japan, Hawaii, Mexico, and America. It is a native element found in the volcanic regions of Japan, Hawaii, Mexico, and America.

ARSENIC

Rhombohedral. Rare in cube-like rhombohedral crystals. Generally found in the form of native arsenic, as well as in the form of various arsenides.

Color. Grey. Lustre. Metallic. Fracture. Conchoidal. Hardness. 2.5. Specific Gravity. 5.7. Taste. Nauseous. Use. In the manufacture of arsenic acid, which is used in the manufacture of many other chemicals.

Comp. Arsenic, often with some antimony, and traces of iron, silver, gold, or bismuth.

Py. 10. In charcoal, it is used in the manufacture of arsenic acid, which is used in the manufacture of many other chemicals.

Obs. Arsenic is found in the form of native arsenic, as well as in the form of various arsenides.

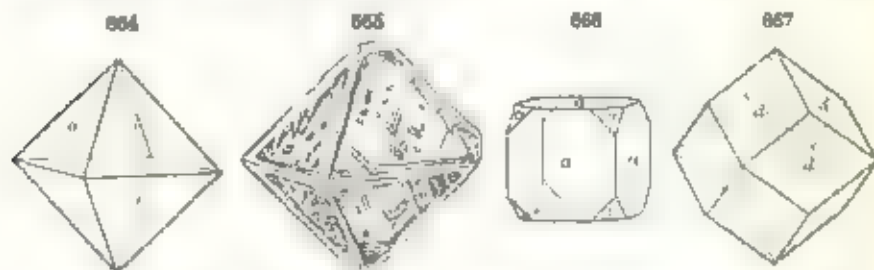
Ar. Arsenic is found in the form of native arsenic, as well as in the form of various arsenides.

Use. An ore of arsenic.

Gold Group

GOLD.

Isometric. X-ray study shows a face-centered cubic lattice (cf. p. 26). Distinct crystals rare *o* {111} most common, also *d* {110} and *m* {111}, crystals often elongated in direction of an octahedral axis, giving rise to rhombohedral-like forms, and arborescent shapes also in plates flattened *h* {111}, and branching at 60° parallel either to the edges or diagonals of an *o* face (see p. 184). Twins: tw plane *o*. Skeletal crystals common, edges salient or rounded, in fibrous, reticulated dendritic shapes. Also massive and in thin laminae, often in flattened grains or scales.



Cleavage none. Fracture hackly. Very malleable and ductile $\Pi = 2 \times 3$. $G = 19.3$ when pure. Luster metallic. Color and streak gold-yellow, sometimes inclining to silver-white and rarely to orange-red. Opaque.

Comp. Gold but usually alloyed with silver in varying amounts and sometimes containing also traces of copper or iron.

Var. 1. *Ornamenta*. Containing up to 16 per cent of silver. Color varying according to the amount of silver, from deep gold-yellow to pale yellow and speckled gray (from 10 to 15 per cent). The ratio of gold to silver of 2:1 corresponds to 15.1 per cent silver. For $G = 19.3$, $Ag = 1$ per cent, $G = 16.4$; $Ag = 13$ per cent, $G = 14.6$; $Ag = 38.4$. The purest gold which has been discovered is the so-called "sponge gold" from Kalgoorlie, West Australia, with 99.91 per cent gold, 0.09 per cent silver.

2. *Verdigris*. Electric. Color pale brown or greenish white, $G = 15.6$ to 15.8. Ratio of gold to silver of 1:1 corresponds to 34 per cent silver. For 1:1, $G = 15.6$; for 1:2, $G = 15.1$; for 1:3, $G = 14.6$. The *verdigris* is a greenish-gray color, and is a product of the action of the atmosphere on the gold-silver alloy.

3. *Verdigris*. Electric. Color pale brown or greenish white, $G = 15.6$ to 15.8. Ratio of gold to silver of 1:1 corresponds to 34 per cent silver. For 1:1, $G = 15.6$; for 1:2, $G = 15.1$; for 1:3, $G = 14.6$. The *verdigris* is a greenish-gray color, and is a product of the action of the atmosphere on the gold-silver alloy.

4. *Verdigris*. Electric. Color pale brown or greenish white, $G = 15.6$ to 15.8. Ratio of gold to silver of 1:1 corresponds to 34 per cent silver. For 1:1, $G = 15.6$; for 1:2, $G = 15.1$; for 1:3, $G = 14.6$. The *verdigris* is a greenish-gray color, and is a product of the action of the atmosphere on the gold-silver alloy.

Diff. — Readily recognized as different from other native elements, also from minerals, by its malleability, its ductility, its high specific gravity, which is not exceeded by any other native element, and its color. It is soluble in aqua regia, and its solution is precipitated by the addition of sodium hydroxide.

Obs. — Gold is always found in the native state. It has been found in various places in the United States, and sometimes in small quantities in the rocks. It is a common element in the rocks, and is frequently associated with other minerals. It is a common element in the rocks, and is frequently associated with other minerals.

The gold which is mined is in the native state. It is found in various places, and in masses which are sometimes an aggregation of small pieces. Frequently the

and west half, some miles (about 10 miles) near Fairview. The gold is located in the ... The chief ... to the ...

The gold deposits are chiefly in the coast ranges in the northern ...

At ... Mexico; the ...

The ... Lake County and from ...

the ...

the ...

the ...

the ...

the ... Lake County and from ...

SILVER.

Isometric. X-ray study shows the silver has a face-centered cubic lattice of ...

... 111 ... streak silver-white ...

Comp. Silver with ... 10 per cent copper and ...

Pre etc ...

Def ... gravity

rocks and may occur in the interior of these as cylindrical lavers. Cananea, Sonora, Mexico.

Obs. - The crystals are usually small, but sometimes of 1/2 inch. They are usually in groups, and are often found in the same place as the native silver. They are often found in the same place as the native silver. They are often found in the same place as the native silver.

Comp. - Pure silver, sometimes containing a little copper.

Py. etc. - It is not very soluble in water, but it is soluble in nitric acid.

Obs. - The crystals are usually small, but sometimes of 1/2 inch. They are usually in groups, and are often found in the same place as the native silver.

Comp. - Pure silver, sometimes containing a little copper.

Py. etc. - It is not very soluble in water, but it is soluble in nitric acid.

Obs. - The crystals are usually small, but sometimes of 1/2 inch. They are usually in groups, and are often found in the same place as the native silver.

Comp. - Pure silver, sometimes containing a little copper.

Py. etc. - It is not very soluble in water, but it is soluble in nitric acid.

MERCURY. Quicksilver

In steel fluid globules scattered through a gangue. Crystals rare. $G_2 = 13.6$ and, therefore, very soluble in water.

Comp. - Pure mercury, Hg , with sometimes a little silver.

Py. etc. - It is not very soluble in water, but it is soluble in nitric acid.

Obs. - The crystals are usually small, but sometimes of 1/2 inch. They are usually in groups, and are often found in the same place as the native silver.

Comp. - Pure mercury, Hg , with sometimes a little silver.

Py. etc. - It is not very soluble in water, but it is soluble in nitric acid.

Obs. - The crystals are usually small, but sometimes of 1/2 inch. They are usually in groups, and are often found in the same place as the native silver.

Comp. - Pure mercury, Hg , with sometimes a little silver.

LEAD

Isometric. Face-centered cubic structure. Crystals rare. Usually in thin plates and small globules. Very malleable and somewhat brittle.

$H = 15.5$, $G_2 = 11.4$. Luster metallic. Color lead-gray. Opaque.

Comp. - Nearly pure lead, sometimes containing a little silver also antimony.

Py. etc. - It is not very soluble in water, but it is soluble in nitric acid.

Obs. - The crystals are usually small, but sometimes of 1/2 inch. They are usually in groups, and are often found in the same place as the native silver.

Comp. - Nearly pure lead, sometimes containing a little silver also antimony.

Py. etc. - It is not very soluble in water, but it is soluble in nitric acid.

Obs. - The crystals are usually small, but sometimes of 1/2 inch. They are usually in groups, and are often found in the same place as the native silver.

AMALGAM

Isometric. Crystals small, but sometimes of 1/2 inch. They are usually in groups, and are often found in the same place as the native silver.

Comp. - Nearly pure lead, sometimes containing a little silver also antimony.

[illegible][illegible]

Indians. It is a rare species, and is found with the porcupine and other animals in the mountains of the silver-white color. H. = 6-7. G. = 22-30. Very rare in the mountains of the Himalayas and in the mountains of the Himalayas. In the mountains of the Himalayas, near Mawlaik, Burma.

TRIBOSMINE *Osmundifera*

Rhombohedral. Axis $c = 1.3823$. Usually an irregular flattened grain.
Cleavage $\{100\}$ perfect. Slightly malleable to nearly brittle. H =
6.7. $d_{100} = 19.3$ 21.12. Luster metallic. Color tin-white to light steel
gray. Opaque.

Comp. In bark and osseum—a different proportions. Some check up platinum, ruthenium, and other metals are usually present.

Var 1: $\text{N} = 11$, $\bar{x} = 18.5$, $s^2 = 15$. In the next column, we write down the deviations from the mean, $x_i - \bar{x}$, and the squared deviations, $(x_i - \bar{x})^2$. The sum of the squared deviations is $\sum (x_i - \bar{x})^2 = 150$. The variance is $s^2 = 150/10 = 15$. The standard deviation is $s = \sqrt{15} \approx 3.87$.

[illegible]

Palladium. In the form of a black powder, which is soluble in aqua regia. It is obtained from the mineral water of the Hot Springs, near the base of the Sierra Nevada, and is described as a black powder, which is soluble in aqua regia. It is obtained from the mineral water of the Hot Springs, near the base of the Sierra Nevada, and is described as a black powder, which is soluble in aqua regia.

rounding error is with minimum difference between adjacent \log_{10} values.

1808.

Isometric. Usually massive, rarely in crystals.
Cleavage {100} perfect. Cubic structure. d_{111} and d_{100} .
Fracture hackly. Mohs' $H = 4.5$; $G = 73.7$. Luster metallic.
Color steel-gray to iron black. Strongly magnetic.

I. Sulphides, etc., of the Semi-Metals

This section includes one distinct group, the Selenite Group, to which Orpiment is related; the other species included stand alone.

REALGAR.

Monoclinic. Axes $a : b : c = 0.7203 : 1 : 0.4858$, $\beta = 68^\circ 15'$.

$$d^{100}, 110 \text{ \AA } 170 = 68^\circ 48'$$

Crystals short prisms, striated vertically. Also granular coarse or fine; compact; as an incrustation.

Cleavage $h\{100\}$, $l\{001\}$ fair. Fracture small conchoidal. Sects. $H = 1.52$, $G = 1.56$, $n = 2.54$, $\beta = 2.65$, $\gamma = 2.70$. Optically Ax. pl. 001 . χ axis $= +11^\circ$. $2V = 40^\circ$. Strong dispersion, $\rho > \sigma$. Luster resublim. Color aurora red or orange-yellow. Streak varying from orange-red to brown-red. Transparent. Translucent. Luster greasy on exposure to light, changing to a mixture of As_2S_3 and As_2O_3 .

Comp. Arsenic monosulphide, $AsS = \text{Sulphur } 29.0$, or same $70.1 = 100$.

Pyrr. etc. In the case of the metals and arsenic, the red color is due to the presence of a small amount of arsenic. In the case of the other metals, the color is due to the presence of a small amount of arsenic. The color is due to the presence of a small amount of arsenic.

And. The color is due to the presence of a small amount of arsenic. The color is due to the presence of a small amount of arsenic. The color is due to the presence of a small amount of arsenic.

Use. This product or a deposit from hot springs.

The product is a deposit from hot springs. The product is a deposit from hot springs. The product is a deposit from hot springs. The product is a deposit from hot springs. The product is a deposit from hot springs.

Use. The product is a deposit from hot springs. The product is a deposit from hot springs. The product is a deposit from hot springs. The product is a deposit from hot springs. The product is a deposit from hot springs.

870



ORPIMENT

Monoclinic. Axes $a : b : c = 0.594 : 1 : 0.665$, $\beta = 89^\circ 10'$. Pseudo-orthorhombic.

Crystals small, rarely distinct. Usually in foliated or columnar masses sometimes with rounded surfaces.

Cleavage $g\{100\}$ fine, perfect; cleavage face vertically striated. $n\{100\}$ in traces. $g\{100\}$ in 001 . Sect. Cleavage $h\{100\}$ in traces. $H = 1.52$, $G = 1.54$, $n = 2.4$, $\beta = 2.5$, $\gamma = 2.6$. Optically Ax. pl. 001 . χ axis $= 70^\circ$. Strong dispersion, $\rho > \sigma$. Luster partly on h cleavage direction resublim. Color brownish yellow of several shades. Streak the same. Luster subtransparent. Slightly translucent.

Comp. Arsenic monosulphide, $As_2S_3 = \text{Sulphur } 50.0$ arsenic $61.0 = 100$.

Comp. — Antimony trisulphide Sb_2S_3 = Sulphur 28.3, antimony 71.7 = 100. Sometimes auriferous, also argenterous.

Pyr. etc. — It does very easily at 1 coloring the flame greenish-blue. In the open tube sulphur fumes, and on subsequent cooling, a green, the color changing as a white, not volatile sublimate of antimony is left. On a strong heat, spreads out, gives sulphurous fumes, and leaves behind a white residue of antimony. The color of the residue is greenish-blue. When pure, it is a white powder, but in nature it is more or less impure, and is sometimes found in a state of decomposition, and is sometimes found in a state of decomposition.

Dist. — The sublimate is from grayish to brown color, and is also in the form of a thin layer, or in small crystals. It is a very fine powder, and is sometimes found in a state of decomposition, and is sometimes found in a state of decomposition.

Artif. — Sublimed. An experiment has been made to sublimate this by heating it in a retort, the neck of which is covered with a paper, and by passing hydrogen sulphide gas at a red heat over it, and it is sublimed.

Obs. — Sublimed. It is the most important antimony mineral, and is the chief source of the metal. It is found in various localities, and is sometimes found in a state of decomposition, and is sometimes found in a state of decomposition. It is sometimes found in a state of decomposition, and is sometimes found in a state of decomposition.

It is sometimes found in a state of decomposition, and is sometimes found in a state of decomposition. It is sometimes found in a state of decomposition, and is sometimes found in a state of decomposition. It is sometimes found in a state of decomposition, and is sometimes found in a state of decomposition.

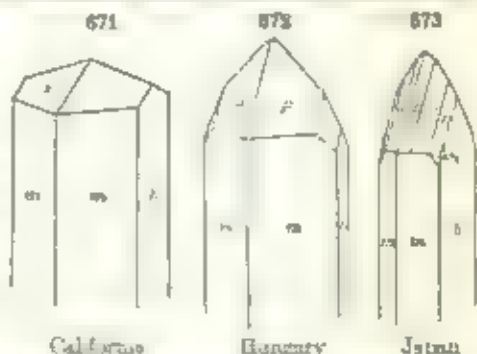
Use. — The most important use of it is in the manufacture of antimony, and is sometimes found in a state of decomposition, and is sometimes found in a state of decomposition.

BISMUTHINITE. Bismuth Glance

Cryst. rhombohedral. Rarely in perfect crystals. mm'' 110 \times 110 \approx 98° S. Usually massive. Cleavage perfect. Somewhat acutic. $H = 2$. $G_r = 1.4$ to 1.5. Lustre metallic. Streak and color lead-gray, changing to iron white with a yellowish or reddish tint. Opacity.

Comp. — Bismuth trisulphide Bi_2S_3 = Sulphur 18.8, bismuth 81.2 = 100. Sometimes contains a little copper and iron.

Antimony. — It is a heavy, bluish-gray mineral, found in various localities, and is sometimes found in a state of decomposition, and is sometimes found in a state of decomposition.



Helenite Montezuma, at Granddun, Boulder Co. Colorado. With hematite and others near Lead Creek, Nevada. *Helen* (H. H. Schuchman). Named from *helen*, fourfold, in allusion to crystals that reveal six faces observed.

Grüningsite. H. 188. Massive. No distinct cleavage. Color gray. $d = 4.321$. From Grönvik, Fe. Cumberland, England. *Grünings* is a similar mineral. H. 188, from Sierra de Ronda, Spain.

Joselite. $\text{Cu}_2\text{Sb}_2\text{S}_5$. Te 80 per cent, also S and Fe. $d = 4.40$. San José, near Matanzas, Matanzas Prov., Cuba.

Wehrliite. As_2S_3 . Te 30 per cent of disulphide formula. $d = 4.4$. From Borzsegy, near Szekesfehervar, Hungary.

MOLYBDENITE.

Hexagonal. $a = 3.916$. Crystals hexagonal in form, tabular or short prisms slightly tapering and horizontally striated. Commonly foliated, massive or in scales. Also fine granular.

Cleavage basal, eminent. Lamine very flexible, but not elastic. Sectile. $H = 1.5$. $G = 4.745$. Luster metallic. Color pure lead-gray, a bluish gray trace on paper, greenish gray on porcelain. Opaque. Feel greasy.

Comp. Molybdenum disulphide, $\text{MoS}_2 = \text{Sulphur } 40.0$ molybdenum 60.0 = 100.

Pyr., etc. In the open to be sulphurous fumes and a small amount of arsenic (to be of molybdenum arsenide). Molybdenum disulphide is a very common mineral. It is found in the form of small crystals, or in the form of scales, or in the form of a fine granular mass. It is a very soft mineral, and is easily scratched with the nail. It is a very greasy mineral, and is easily rubbed with the finger. It is a very common mineral, and is found in many localities. It is a very important mineral, and is used in many industries.

Dif. Molybdenum disulphide is a very common mineral. It is found in the form of small crystals, or in the form of scales, or in the form of a fine granular mass. It is a very soft mineral, and is easily scratched with the nail. It is a very greasy mineral, and is easily rubbed with the finger. It is a very common mineral, and is found in many localities. It is a very important mineral, and is used in many industries.

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Use. An important ore of molybdenum. It is used in many industries.

Tungstenite. WS_4 . $H = 1.5$. $G = 8.0$. Color black to lead-gray.

Patronite. As_2S_3 . $H = 1.5$. $G = 4.745$. Color black to lead-gray. It is a very common mineral, and is found in many localities. It is a very important mineral, and is used in many industries.

RENTHEIM ANIMATED The new film is set in Lake Superior apparently contains
 a very large lake. As to the other two, they are not as good as the first.

Horseshoe $\frac{1}{2}$ lb. 1.00

Domoykite

Lake Superior, Ontario.

1. Mr. J. H. Smith, 1234 Main St., Springfield, Mass.
 2. Mr. J. H. Smith, 1234 Main St., Springfield, Mass.
 3. Mr. J. H. Smith, 1234 Main St., Springfield, Mass.
 4. Mr. J. H. Smith, 1234 Main St., Springfield, Mass.
 5. Mr. J. H. Smith, 1234 Main St., Springfield, Mass.
 6. Mr. J. H. Smith, 1234 Main St., Springfield, Mass.
 7. Mr. J. H. Smith, 1234 Main St., Springfield, Mass.
 8. Mr. J. H. Smith, 1234 Main St., Springfield, Mass.
 9. Mr. J. H. Smith, 1234 Main St., Springfield, Mass.
 10. Mr. J. H. Smith, 1234 Main St., Springfield, Mass.

Agonizante

W. 1918. The superposition of the 1918-1919 and 1919-1920
for which the 1918-1919 and 1919-1920 seasons have been
for the 1918-1919 and 1919-1920 seasons.

COMPLETLY PORTABLE AND CAPABLE OF BEING A SUPERMARKET OF NATURAL

[illegible]

$\frac{1}{2} \log \frac{1}{2} = -0.5$

Work schedule: _____

1. The first step is to identify the variables that are being measured. In this case, the variables are the number of hours spent on each activity and the total number of hours available.

[illegible]

Leptocarpus, sylvanensis, poeppigii, richardsonii

Machete

From: [redacted] To: [redacted]
Subject: [redacted]

$\frac{d}{dt} \left(\frac{1}{2} m v^2 + U(r) \right) = 0$

B. Monosulphides, Monotellurides, etc., $RS \cdot HS$, etc.

1. Isometric

Galena Group

Galena	Pb
Asso.	Pb, Fe, Cu, Ag, Bi, Zn
Albite	Na
Clausthalite	Pb

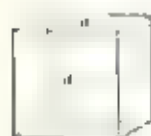
ArgenteLife Group

Argentite	Ag ₂ S
Bessite	Ag ₃ Tl
Aquilarite	Ag ₂ Se
Naumannite	Ag ₂ P
Eucrite	Cl ₂ Ag ₂ As ₂

GALENA. GALENITE. Lead Glance.

Crystal. Structure according to a face-centered cubic lattice. Commonly, cubical, or octahedral, but also, less often, octahedral. Also in slender prisms, hexagonal, and in twins. Two principal cleavages, {100} and {111}, with perfect interpenetrations. (See Page 427, 430, pp. 186-187, and sometimes repeated, twin crystals after cleavage.) Also other cleavages giving poor surfaces. Twin lines are. May be of visible, coarse or fine granular to impalpable, occasionally fibrous or plumose.

674



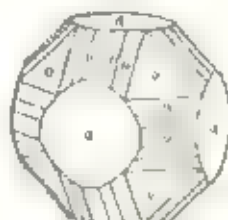
675



676



677



p. 421, fig. 100

Fracture. Conchoidal, but often perfect, less often on octahedral parting. Transverse the subcubical, at angles $H = 25-275^\circ$, $A = 74-76^\circ$. Luster metallic. Color indistinct pure and gray. (Page 1.)

Comp. Lead sulphide. (See Sulphur 131, and 86 B, 100, 196 for german silver and for specially selected zinc compounds, brass, bismuth, copper, amalgams, leadals, also sometimes native silver and gold.)

Var. *Chalcopryite* is a form of lead sulphide, but is a somewhat distinct mineral, especially when it is associated with copper. It is a form of lead sulphide, but is a somewhat distinct mineral, especially when it is associated with copper. It is a form of lead sulphide, but is a somewhat distinct mineral, especially when it is associated with copper.

Pyrrhotite is a form of lead sulphide, but is a somewhat distinct mineral, especially when it is associated with copper. It is a form of lead sulphide, but is a somewhat distinct mineral, especially when it is associated with copper.

Galena is a form of lead sulphide, but is a somewhat distinct mineral, especially when it is associated with copper. It is a form of lead sulphide, but is a somewhat distinct mineral, especially when it is associated with copper.

Pyr. In the pyrrhotite group, but is a somewhat distinct mineral, especially when it is associated with copper. It is a form of lead sulphide, but is a somewhat distinct mineral, especially when it is associated with copper.

Blf. In the blende group, but is a somewhat distinct mineral, especially when it is associated with copper. It is a form of lead sulphide, but is a somewhat distinct mineral, especially when it is associated with copper.

After. In the after group, but is a somewhat distinct mineral, especially when it is associated with copper. It is a form of lead sulphide, but is a somewhat distinct mineral, especially when it is associated with copper.

Anal. In the anal group, but is a somewhat distinct mineral, especially when it is associated with copper. It is a form of lead sulphide, but is a somewhat distinct mineral, especially when it is associated with copper.

Obs. In the obs group, but is a somewhat distinct mineral, especially when it is associated with copper. It is a form of lead sulphide, but is a somewhat distinct mineral, especially when it is associated with copper.

thinks, calcite, etc. betwixt calcite and quartz, and turquoise, quartz, calcite and sulphate.

ARGENTITE. Silver Glance.

Isometric. Crystals cubic and several other forms often distorted from cube. It grows in the veins of argentiferous pyrites, also in form of small, rounded, as a coating.

Ag₂S. It is a blackish grey, metallic, and is very brittle. It is very soft, and is easily scratched with a knife. It is very lustrous, and is very soluble in aqua regia.

Chemical analysis. H = 2.2, C = 7.20, S = 1.0. It is very soluble in aqua regia, and is very soluble in aqua ammonia. It is very soluble in aqua ammonia, and is very soluble in aqua ammonia.

Comp. Sulphur 12.0, Ag = 87.1 = 100.

Pyr. etc. It is very soluble in aqua ammonia, and is very soluble in aqua ammonia. It is very soluble in aqua ammonia, and is very soluble in aqua ammonia.

After. Alloys to native silver, silver sulpho-salts, etc.

And. Ag₂S. It is very soluble in aqua ammonia, and is very soluble in aqua ammonia. It is very soluble in aqua ammonia, and is very soluble in aqua ammonia.

Obs. Ag₂S. It is very soluble in aqua ammonia, and is very soluble in aqua ammonia. It is very soluble in aqua ammonia, and is very soluble in aqua ammonia.

Use. It is very soluble in aqua ammonia, and is very soluble in aqua ammonia. It is very soluble in aqua ammonia, and is very soluble in aqua ammonia.

Heats. It is very soluble in aqua ammonia, and is very soluble in aqua ammonia. It is very soluble in aqua ammonia, and is very soluble in aqua ammonia.

Pellets. Ag₂S. It is very soluble in aqua ammonia, and is very soluble in aqua ammonia. It is very soluble in aqua ammonia, and is very soluble in aqua ammonia.

Agallite Silver selenide Ag_2Se and Ag_2Te . In skeleton dodecahedral crystals. Sects $d = 7.5\mu$, color blackish. From Lander, Nevada.

Naumannite Silver telluride Ag_2Te . In cubic crystals, also massive, granular in thin plates. Lead-gray color ($d = 6.0$). Color and streak brown-black. From Lander in the Hartz Mts. (Germany). Crystallography in part as in the Lander, (Owens) to Idaho, and considered to be argentite. Very metastable and unstable. $d = 5.5$, $\rho = 7.5$.

Berzeliante Copper selenide Cu_2Se . In tetrahedral structure. In thin plates, crystals also, section of $d = 0.7$, color silvery white, turning from blackish, near Freyberg, Saxony, Germany, Lander, Hartz Mts. (Germany).

Eucrite $\text{Cu}_2\text{Ag}_2\text{Se}$. In massive, granular $d = 7.40$. Color between black and lead-gray. From Lander, Saxony, near Freyberg, Saxony, Germany, from near Opago, Nevada, and the Sierra de Riva, Argentina.

Crookesite - Selenium of copper and thallium, also silver, 1.6 per cent. $\text{Cu}, \text{Ag}, \text{Se}$. Massive, compact, $d = 6.4$. Lander, Nevada. Color lead-gray. From the same of Saxony, near Freyberg, Saxony, Germany.

Umanite $\text{Cu}_2\text{Ag}_2\text{Se}$. Massive, fine-grained to compact. $H = 3$, $d = 6.620$. Near dark brown-red. From Lander, Argentina.

Kubanite Cu_2Se . Crystals hexagonal and isomorphous with covellite. Crystals in massive, silvery-gray, color. From Sierra de Riva, Argentina and the Hartz Mts. (Germany). Section of $d = 0.7$, color blackish, turning from blackish, near Freyberg, Saxony, Germany.

Pennacite FeCu_2S . Cu_2S phase. $\text{N}, \text{Cu}, \text{S}$, orthorhombic. Perfect cleavage $d = 0.1$, $d = 0.1$, $d = 0.1$, cleavage of $d = 0.1$ structure. Lead-gray color. $d = 6.60$, $H = 3$. Probably from Lander, Nevada.

2. Chalcocite Group

		a	b	c
Chalcocite	Cu_2S	0.5622	1	0.9701
Stromeyerite	$\text{Ag}_2\text{Cu}_2\text{S}$	0.5822	1	0.9608
Stannite	$\text{Ag}_2\text{Sn}_2\text{S}$	0.5832	1	0.9601
Acanthite	Ag_2S	0.6886	1	0.9944

The species of the **CHALCOCITE GROUP** crystallize in the orthorhombic system, with a prismatic angle approximating to 60° , they are hence pseudo-hexagonal in form, especially when twinned. The group is parallel to the Argentite group, since Cu_2S like Ag_2S has a high temperature rhombohedral form and a low temperature orthorhombic form. Some authors include *Cysaite* here (see p. 414).

CHALCOCITE Copper Glance. Rhombohedral.

Orthorhombic. Axes $a : b : c = 0.5822 : 1 : 0.9701$

$$\begin{aligned} \text{mm} \quad & a : b : c = 60 : 100 : 97 \\ & a : b : c = 125 : 25 : 97 \end{aligned} \quad \begin{aligned} \text{cp} \quad & 0.01 \angle 111 = 62^\circ 34' \\ & 111 \angle 111 = 83^\circ 34' \end{aligned}$$

Crystals pseudo-hexagonal in angle, also by twinning (see p. 116). Rarely twinned on (012) or (112). Often massive, structure granular to compact and unspalable.

Cu_2S is dimorphic. Above 91°C the orthorhombic form changes to an isometric modification. Acid crystals of the latter show cube and octahedron with twinning on (111).

Cleavage $m(110)$ indistinct. etching of orientated crystals develops cleavages parallel to the three pinacoids. Fracture conchoidal. Rather brittle. $H = 2.5-3$, $G = 5.5-5.8$ (5.785 for artificial mineral). Luster metallic. Color and streak blackish lead-gray, often tarnished blue or green, dull. Opaque.

Cubanite. Chalcosite $\text{CuS Fe}_2\text{S}_3$. Orthorhombic. Axial ratio near that of chalcosite. In thin slabs of prism, vertically striated. Twinned commonly with 110 as the p resembling chalcosite. $H = 3\frac{1}{2}$; $G = 4\frac{1}{2}$; not brittle to granular in low. Strong yellow. Cleavage was originally described from 100 mm. Cu is later iron. Tschermak and Kretz of a Swedish *sublimaria* from the Morris silver mine, Minas Geraes, Brazil and Prince William Sound, Alaska. The two appear to be identical.

STERNBERGITE

Orthorhombic. Crystals tabular (100). Commonly in fan-like aggregations, twins, tw. pl. on 110. Cleavage (100) highly perfect. Thin laminae flexible, like tin-foil. $H = 3\frac{1}{2}$; $G = 4\frac{1}{2}$ to 5. Luster metallic. Color pinetree-brown. Streak black. Opaque.

Comp. AgFeS₂ or Ag₂FeS₂ = Sulphur 30.4, silver 34.2, iron 35.4 = 100.

It appears probable that small and varying amounts of FeS and S may be held in solid solution and the *composition* and *order* of atoms from Johannsthal and a pyrrhotite from Freiberg are varieties of sternbergite.

Obs. Occurs with pyrrhotite and stannite at Johannsthal, Bohemia, and Johann-georgenstadt, Saxony.

Acanthite. Silver sulphide, Ag₂S, like argenteite. For reactions to argenteite, see below that variety, p. 118. Orthorhombic. In slender prisms, *composition* $G = 4\frac{1}{2}$; $H = 3\frac{1}{2}$. Color pinetree-brown. Found at Johannsthal, Freiberg, Saxony, in Saxony near Freiberg, and elsewhere. In California and Zacatecas, Mexico. Reported in Colorado from Georgetown and Rio.

3. Sphalerite Group. RS. Isometric-tetrahedral

Sphalerite	ZnS	Osofrite	$\text{Hg}_2\text{S}_2\text{S}$	
Metcunnabarite	Hg_2S	Coloradoite	Hg_2S	Massive
Gersdorffite	Hg_2ZnS			
Tiemannite	Hg_2S			

The SPHALERITE Group embraces a number of sulphides, selenides, etc. of zinc, mercury, and copper. These are isometric-tetrahedral in crystallization. X-ray study shows the similarity in atomic structure of the above members of the Sphalerite Group.

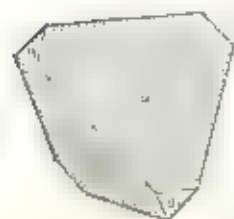
SPHALERITE, Zinc blende or Blende. Blackish. Mock Lead. False Galena.

Isometric-crystal. Atomic structure similar to that of diamond of p. 40, with Zn and S atoms alternately taking the position of the C

681

682

683



$n = 411$

atoms. Often in tetrahedrons, the positive and negative terms frequently showing differences in luster, etching lines, etc. Cubic, dodecahedron, and

tristetrahedron forms also present at times. Twins common: tw. pl. of (111), tw. lining often repeated, sometimes as polysynthetic lamellae. Crystals often distorted or rounded. Color usually massive grayish, coarse to fine granular and compact, also foliated, sometimes fibrous and radiated or plumose, also botryoidal, and other invasive shapes. Cryptocrystalline to amorphous, the latter sometimes as a powder.

Cleavage dodecahedral, highly perfect. **Fracture** conchoidal. **Brittle**. **H** = 3-5. **G** = 3.9-4.1, 4.063 white, New Jersey. **Luster** resinous to adamantine. **Color** commonly yellow, brown black also red, green to white, and when pure nearly colorless. **Streak** brownish to light yellow and white. **Transparent to translucent**. **Refractive index** high: $n = 2.370-2.423$, rising with increase of iron contents. Some varieties will phosphoresce when scratched etc.

Comp. Zinc sulphate, $ZnS = \text{Sulphur } 33, \text{ zinc } 67 = 100$. Often containing iron and manganese, and some times calcium, mercury and rarely lead and tin. Also sometimes contains traces of indium, gallium and thallium, may be argentiferous and stanniferous.

[illegible]
$$C_1 = \frac{1}{2} \left(\frac{1}{2} + \frac{1}{2} \right) = \frac{1}{2} \quad \text{and} \quad C_2 = \frac{1}{2} \left(\frac{1}{2} + \frac{1}{2} \right) = \frac{1}{2}$$

The amount of radiocesium present in dry sphalerite (that

[illegible]

Diff. V^{2+} and V^{3+} ions are present in the reaction product. In a subsequent step, the reaction product is heated in air, which yields a zinc oxide coating on charcoal.

And I have a feeling that the only way to get the best of the situation is to get the best of the situation.

Q. Did you find any other evidence of the murder?

1. 1988 年 12 月 25 日，在北京市召开了“1988 年中国人口科学大会”。会议期间，中国科学院人口研究所、中国人口学会、中国人口出版社等单位联合举办了“1988 年中国人口科学大会”。

$\frac{d}{dt} \left(\frac{\partial L}{\partial \dot{x}} \right) = \frac{\partial L}{\partial x}$

[Faint, illegible handwritten notes]

the temporal in whereas that of warlike

for the purpose of the investigation.

He arrived in New York in the year 1841 at the time of the first meeting of the American Association of the Friends of the Slave.

PENTLANDITE.

Isometric. Massive, granular. Cleavage octahedral. Fracture uneven. Brittle. $H = 3.5-4$ $G = 5.0$. Luster metallic. Color light bronze-yellow. Streak light bronze-brown. Opaque. Not magnetic.

Comp. A sulphide of iron and nickel, $(Fe,Ni)_9S_{16}$. In part, $2FeS:NiS = S_{16}$:phur 36.0 iron 42.0, nickel 22.0 = 100.

Obs. Pentlandite commonly occurs intergrown with pyrrhotite and associated also with magnetite, arsenic pyrrhotite, marcasite and chalcopyrite. In Norway it occurs with chalcopyrite at Capekallur, Artveit, Luleå, and elsewhere. It occurs with pyrrhotite in the Sudbury district, Ontario, Canada, intimately associated with nickeliferous pyrrhotite. It can be distinguished from the latter by its cleavage.

4. Rhombohedral or Hexagonal Group

Cinnabar	HgS	Rhombohedral-Trapezohedral	$\frac{c}{a} = 1.1453$	
Greenockite	CdS	Hexagonal Hemimorphic	$\frac{c}{a} = 0.8109$ or 0.9364	
Wurtzite	ZnS	"	0.8175	0.9440
Millerite	NiS	Rhombohedral		0.9883
Nickelite	$NiAs$	Hexagonal	0.8104	0.9462
Breithauptite	$NiSb$	"	0.8586	0.9915
Arsite	$NiSb,As$			
Pyrrhotite	$Fe_{9-10}, etc.$	Hexagonal	0.8761	1.0047
Troilite	FeS			
Covellite	CuS		1.1486	

The fourth group among the monosulphides includes several subdivisions, as shown in the scheme above, and the relations of the species are not in all cases perfectly clear. It is to be noted that the sulphides of mercury and zinc, already represented in the sphalerite group, appear here again. A ray study has revealed new relationships between these minerals but has not yet clearly defined the whole group. Covellite has been shown to have a structure similar to pyrrhotite although its axial ratio is more nearly related to that of cinnabar. Nickelite and breithauptite differ in their structure from millerite and show relationships to greenockite and wurtzite. In some cases the present accepted value for c/a differs from that given above, but usually only in being a multiple or simple fraction of that given. The former values are retained in order to show that whatever minor differences exist in the relations between the members of the group they do have striking crystallographic characters in common.

If, as suggested by Goldf., the prominent pyramids of wurtzite (or greenockite, etc.) be taken as the basis of the crystal system $a = 1$ (22° , angle of 1011), then the values of c/a for the second column are obtained, which correspond to values c . The ratio of c/a between these species, however, is not perfectly known. A rhombohedral form of greenockite has been suggested. Zincite (ZnO) shows close structural relations to greenockite and wurtzite.

Violarite. — A nickel sulphide. Comp. given either as NiS_2 and then assumed to have simple structure as a result of material which has been shown to belong to Pyrite Group or more probably as Ni_3S_4 , in which the group with arsenic. Perfect in a few cases. Luster vitreous. Fracture conchoidal to irregular. Associated with pyrite, chalcopirite and pyrrhotite in the Iron-ore zone, Lake Co., New York, as a replacement of pentamolybdenite. Occurs in small veins in south-western Alaska. Reported from Sudbury, Ontario, see under pyrrhotite and arsenic and iron.

Polyimite. Nickel tetrathionate NiS_4 . In octahedral crystals (freedom the twinned form) are made up of NiS_4 or NiS_2 . $C = 4.64-4.81$. Color gray. From the turquoise mine, southwest of Schuchthaus, and southeast of Wissen, in the Sleg, Bavaria. The polyimite is reported from Sudbury, Ontario, and is of a different character. It has been stated to be a variety of arsenic and is a violarite, but this conclusion has been disputed.

Dandreeite. An iron-chromium sulphide, FeCr_2S_4 , occurring with troilite in some iron-ore zones. Color black. $C = 5.6$.

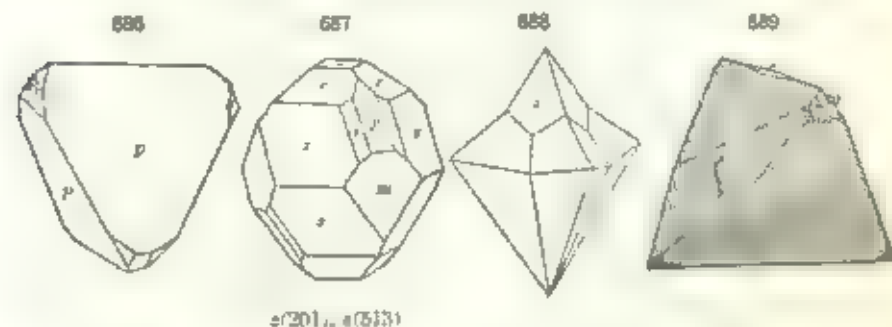
Badenite. FeS_2 , AsS_2 ? Massive granular to fibrous. $C = 7.1$. Metallic. Color steel-gray. Fracture conchoidal to irregular. District of Maceo, Romania, associated with orthopyrite, arsenopyrite, malachite, siderite.

CHALCOPYRITE. (Copper Pyrites. Yellow Copper Ore.)

Tetragonal-sphenoidal. Axis $c = 0.98525$

$pp. 111 \wedge \Pi = 105^\circ 40'$ $pp. 111 \wedge \Pi = 70^\circ 71'$ $\alpha(001) \wedge 101 = 44^\circ 34'$

Crystals commonly tetrahedral in aspect, the sphenoidal faces $p(111)$ large, dull or oxidized, $p, 111$ small and brilliant. Some cases both forms equally developed, and then octahedra in form. Twins (1) tw $p(111)$,



resembling spinel-twins (Fig. 443, p. 188) sometimes repeated as a fivefold (Fig. 688). 2 Tw $p(111)$ and comp-face $\alpha(101)$ (Fig. 689) often in repeated twins. 3 Tw $p(111)$, tw axes complementary penetration twins. X-ray analysis shows that the structure is similar to that of sphalerite, the layers of zinc atoms in that mineral being replaced by alternate layers of copper and iron atoms. Often massive compact, sometimes botryoidal or reniform.

Cleavage $\alpha(201)$, sometimes distinct. Fracture uneven. Brittle. $H = 3.5-4$. $G = 4.1-4.3$. Luster metallic. Color brass-yellow, often tarnished or iridescent. Streak greenish black. Opaque.

Comp. A sulphide of copper and iron, $\text{CuFeS}_2 = \text{Sulphur } 35.0$, copper 34.5, iron 30.5 = 100. Analyses often show variations from this formula, often due to mechanical admixture of pyrite.

Pyrite Group. RS_2 , RAs_2 , RSb_2 Isometric-pyritohedral or -tetartohedral

Pyritohedral		Tetartohedral	
Pyrite	FeS_2	Cobaltite	$CoAsS$
Bravoite	$(Fe, Ni)_2S_2$	Gersdorffite	$NiAsS$
Cobaltmickelpyrite	$(Co, Ni, Fe)_2S_2$	Ulmannite	NbS_2S
Hauerite	MnS_2		
Arsenoferrite	$FeAs_2$	Laurite	RuS_2
Sperryite	$PtAs_2$	Smaltite	$CoAs_2$, also $(Co, Ni)As_2$
		Chloanthite	$NiAs_2$, also $(Ni, Co)As_2$
		Skutterudite	$CoAs_3$

Marcasite Group. RS_2 , RAs_2 , etc. Orthorhombic

		a	b	c	$110^\circ \wedge (10)$	$101^\circ \wedge 101$
Marcasite	FeS_2	0.7682	1	1.2342	$74^\circ 55'$	$116^\circ 20'$
Lollingite	$FeAs_2$	0.6689	1	1.2331	$67^\circ 33'$	$123^\circ 3'$
Safflorite	$CoAs_2$					
Rammelsbergite	$NiAs_2$					
Arsenopyrite	$FeS, FeAs_2$	0.6773	1	1.1882	$68^\circ 13'$	$120^\circ 38'$
Dannite	$(Fe, Co)_2S_2, (Fe, Co)As_2$					
Glaucodot	$(Co, Fe)_2S_2, (Co, Fe)As_2$	0.6942	1	1.1925	$69^\circ 32'$	$119^\circ 35'$
Wolfchute	$Nb_2S_7, NbAs_2, Sb_2$					

The PYRITE GROUP includes, besides, the compounds of Fe, Co, Ni, also others of the related metals Mn and Pt. The crystallization is isometric-pyritohedral. X-ray analysis shows clearly the same structure for pyrite, sperryite, cobaltite, gersdorffite and ulmannite, the last three, however, showing tetartohedral symmetry. Smaltite-chloanthite and skutterudite though probably pyritohedral and closely related to each other do show structural differences from pyrite.

The species of the MARCASITE GROUP crystallize in the orthorhombic system with prismatic angles of about 70° and 110° and a prominent macrodome of about 60° and 120° . Hence fivefold and sixfold repeated twins are common with several species, in the one case the prism and in the other the macrodome named being the twinning plane. X-ray analysis shows closely related structures for the members of this group, lollingite, safflorite and rammelsbergite have identical structures as also have arsenopyrite and glaucodot. Further the structure is closely related both to isometric and tetragonal (rutile) structures.

Pyrite Group**PYRITE.** Iron Pyrites

Isometric-pyritohedral. Cube and pyritohedron $\{210\}$ the common forms, the faces of both often with striations—edge a 100° $\{210\}$ due to oscillatory combination of these forms or tending to produce rounded faces, pyritohedral faces also striated \perp to this edge, octahedron also common. See Figs. 690-695, also Figs. 151-156 pp. 81-82. Twins tw pl = (110) and tw ax normal to this face, usually penetration-twins (Fig. 433, p. 187), rarely contact-twins. For illustration of atomic structure see p. 41. Frequently massive, fine granular, sometimes subfibrous radiated, reniform, globular, stalactitic.

traces of these metals, the results of which have been found in a number of places. The results of the analysis of the ore are as follows:—

Analysis of the ore from the mine at Chiboutou, near the mouth of the Rio de la Platte, in the Province of Buenos Aires, in the Argentine Republic, shows the presence of the following elements:—

Gold, 1.5 per cent. Silver, 0.5 per cent. Copper, 1.0 per cent. Iron, 1.0 per cent. Lead, 1.0 per cent. Zinc, 1.0 per cent. Nickel, 1.0 per cent. Cobalt, 1.0 per cent. Manganese, 1.0 per cent. Arsenic, 1.0 per cent. Antimony, 1.0 per cent. Tellurium, 1.0 per cent. Selenium, 1.0 per cent. Sulfur, 1.0 per cent. Oxygen, 1.0 per cent. Hydrogen, 1.0 per cent. Nitrogen, 1.0 per cent. Phosphorus, 1.0 per cent. Potassium, 1.0 per cent. Sodium, 1.0 per cent. Calcium, 1.0 per cent. Magnesium, 1.0 per cent. Barium, 1.0 per cent. Strontium, 1.0 per cent. Bismuth, 1.0 per cent. Vanadium, 1.0 per cent. Chromium, 1.0 per cent. Molybdenum, 1.0 per cent. Tungsten, 1.0 per cent. Rhenium, 1.0 per cent. Iridium, 1.0 per cent. Platinum, 1.0 per cent. Palladium, 1.0 per cent. Rhodium, 1.0 per cent. Ruthenium, 1.0 per cent. Zirconium, 1.0 per cent. Niobium, 1.0 per cent. Tantalum, 1.0 per cent. Vanadium, 1.0 per cent. Chromium, 1.0 per cent. Manganese, 1.0 per cent. Iron, 1.0 per cent. Cobalt, 1.0 per cent. Nickel, 1.0 per cent. Copper, 1.0 per cent. Silver, 0.5 per cent. Gold, 1.5 per cent.

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Gold, 1.5 per cent. Silver, 0.5 per cent. Copper, 1.0 per cent. Iron, 1.0 per cent. Lead, 1.0 per cent. Zinc, 1.0 per cent. Nickel, 1.0 per cent. Cobalt, 1.0 per cent. Manganese, 1.0 per cent. Arsenic, 1.0 per cent. Antimony, 1.0 per cent. Tellurium, 1.0 per cent. Selenium, 1.0 per cent. Sulfur, 1.0 per cent. Oxygen, 1.0 per cent. Hydrogen, 1.0 per cent. Nitrogen, 1.0 per cent. Phosphorus, 1.0 per cent. Potassium, 1.0 per cent. Sodium, 1.0 per cent. Calcium, 1.0 per cent. Magnesium, 1.0 per cent. Barium, 1.0 per cent. Strontium, 1.0 per cent. Bismuth, 1.0 per cent. Vanadium, 1.0 per cent. Chromium, 1.0 per cent. Molybdenum, 1.0 per cent. Tungsten, 1.0 per cent. Rhenium, 1.0 per cent. Iridium, 1.0 per cent. Platinum, 1.0 per cent. Palladium, 1.0 per cent. Rhodium, 1.0 per cent. Ruthenium, 1.0 per cent. Zirconium, 1.0 per cent. Niobium, 1.0 per cent. Tantalum, 1.0 per cent. Vanadium, 1.0 per cent. Chromium, 1.0 per cent. Manganese, 1.0 per cent. Iron, 1.0 per cent. Cobalt, 1.0 per cent. Nickel, 1.0 per cent. Copper, 1.0 per cent. Silver, 0.5 per cent. Gold, 1.5 per cent.

The results of the analysis of the ore from the mine at Chiboutou, near the mouth of the Rio de la Platte, in the Province of Buenos Aires, in the Argentine Republic, shows the presence of the following elements:—

Gold, 1.5 per cent. Silver, 0.5 per cent. Copper, 1.0 per cent. Iron, 1.0 per cent. Lead, 1.0 per cent. Zinc, 1.0 per cent. Nickel, 1.0 per cent. Cobalt, 1.0 per cent. Manganese, 1.0 per cent. Arsenic, 1.0 per cent. Antimony, 1.0 per cent. Tellurium, 1.0 per cent. Selenium, 1.0 per cent. Sulfur, 1.0 per cent. Oxygen, 1.0 per cent. Hydrogen, 1.0 per cent. Nitrogen, 1.0 per cent. Phosphorus, 1.0 per cent. Potassium, 1.0 per cent. Sodium, 1.0 per cent. Calcium, 1.0 per cent. Magnesium, 1.0 per cent. Barium, 1.0 per cent. Strontium, 1.0 per cent. Bismuth, 1.0 per cent. Vanadium, 1.0 per cent. Chromium, 1.0 per cent. Molybdenum, 1.0 per cent. Tungsten, 1.0 per cent. Rhenium, 1.0 per cent. Iridium, 1.0 per cent. Platinum, 1.0 per cent. Palladium, 1.0 per cent. Rhodium, 1.0 per cent. Ruthenium, 1.0 per cent. Zirconium, 1.0 per cent. Niobium, 1.0 per cent. Tantalum, 1.0 per cent. Vanadium, 1.0 per cent. Chromium, 1.0 per cent. Manganese, 1.0 per cent. Iron, 1.0 per cent. Cobalt, 1.0 per cent. Nickel, 1.0 per cent. Copper, 1.0 per cent. Silver, 0.5 per cent. Gold, 1.5 per cent.

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BIAMITO-SMALTITE $\text{Cu}_2\text{As}_2\text{S}_4$. A arsenic sulfide containing bismuth. Color tin-white. $G. = 4.92$. Zachowia, near Schneeberg, Saxony.

Marcasite Group

For the list of species and their relations, see p. 433.

MARCASITE. White iron pyrites.

Orthorhombic. Axes $a : b : c = 0.7682 : 1 : 1.2342$

$\alpha = 110^\circ 11'$, $\beta = 74^\circ 56'$.

$\gamma = 131^\circ 10'$, $\delta = 116^\circ 20'$

$h k l : 011 \wedge 0\bar{1}1 = 101^\circ 59'$

$c : 001 \wedge 111 = 63^\circ 49'$

Twins: tw. pl. $m(110)$, sometimes in stellate twilings (Fig. 462, p. 191, cf. Fig. 697), also tw. pl. $e(101)$, less common, the crystals crossing at angles

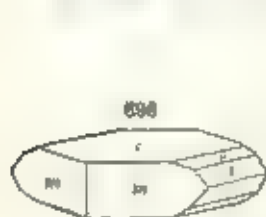


Fig. 697

of nearly 60° . Crystals commonly tabular $\{c(001)\}$, also pyramidal, the brachy-axes striated edge $h(110) \wedge 001$. Often massive, radiating fibrous in stalactites; also globular, reniform, and other unitive shapes.

Cleavage $m(110)$, poor; $k(011)$ in traces. Fracture uneven. Brittle.

$H. = 6-6.5$. $G. = 4.85-4.90$. Luster metallic. Color pure bronzy-yellow, deepening on exposure. Streak grayish or brownish black. Opaque.

Comp. Iron disulfide, as pyrite, and = sulphur 53.4, iron 46.6 = 100. Arsenic is sometimes present in small amount.

Var. — The varieties named depend mainly on state of crystallization. *Radial* (Cockcomb Pyrite). Aggregations of fibrous twinned crystals spear-like, thus *Spear Pyrite*. Two crystals with faces crossing angles a little like the head of a spear in iron (Fig. 697, *capillary*). In capillary crystallizations.

Pyrr., etc. — Like pyrite. Very liable to decomposition, more so than pyrite.

Diff. — Marcasite is a little harder than pyrite, and is gray when fresh (e.g. after iron has been polished), when pyrite and easily distinguished by the form. Moreover, pyrite turns red and becomes blacker than pyrite.

Marcasite can be distinguished chemically from pyrite by the following methods. When both are ground fine, and heated as heated with a little concentrated sulphuric acid in the cold and later after vigorous action has ceased, the cooling it will be found that in the case of pyrite the greater part of the sulphur is evolved and has been reduced and taken down as sulphur and white smoke caused by the acid fumes and the only way to separate in a free state. The Stokes method which can be used quantitatively to determine the amount of the two elements is as follows. Place a upon the difference in their behavior when heated with a strong solution of ferric sulphate. In the case of pyrite about 5 per cent of the sulphur is evolved as ferric sulphate, while in the case of marcasite only about 2 per cent is evolved. Another method consists in heating the minerals in a 1 per cent solution of AgNO_3 , when marcasite will be transformed into a brown color, then red and finally blue, whereas pyrite becomes only slightly brownish.

Alt. — Marcasite being more easily oxidized is easily altered. Sperrmann often distinguishes it by the formation of ferric sulphate and sulphuric acid. It also alters to pyrite, limonite, etc.

Obs. — Marcasite is a much less stable compound than pyrite and is formed under comparatively unusual conditions. Experiments have shown that it is dependent on temper-

states have been found in the same place. The higher the percentage of selenium the more the arsenic content. The arsenic content of the arsenides is usually between 10 and 20 per cent. The arsenides are usually found in the same place as the arsenides.

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ARSENOPYRITE, or MISFICKEL.

Orthorhombic. Arsenic content 0.6-1.1. 1882. X-ray study shows that the arsenic content corresponds to that when arsenic is present, except that the length of a should be 10.000.

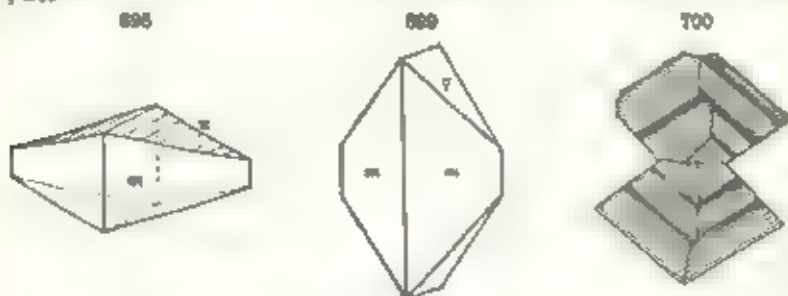
$$100^{\circ}, 110 \wedge 110 = 66^{\circ} 13'.$$

$$100^{\circ}, 014 \wedge 014 = 33^{\circ} 5'.$$

$$100^{\circ}, 012 \wedge 012 = 33^{\circ} 5'.$$

$$99^{\circ}, 011 \wedge 011 = 99^{\circ} 50'.$$

Twins: tw pl $m(110)$, sometimes repeated like marcasite (Figs. 700 and 463, p. 191), $c(101)$, cruciform twins, also trillings (Figs. 458, 459, p. 191). Crystals prismatic $m(110)$ or flattened vertically by the oscillatory combination of brachydoises. Also columnar, straight, and divergent, granular, or compact.



Cleavage $m(110)$ rather distinct $c(001)$ in faint traces. Fracture uneven. Brittle. $H = 5.5-6$. $G = 5.9-6.2$. Luster metallic. Color silver white, inclining to steel-gray. Streak dark gray to black. Opaque.

Comp. Sulpharsenide of iron, $FeAs_2$ or less $FeAs_3 = \text{Arsenic 36.0, sulphur 19.7 iron 34.3} = 100$. Part of the iron is sometimes replaced by cobalt, as in the variety *danube* (3 to 9 per cent Co).

Pyr., etc. In the closed tube may give at first a little yellow or bluish of arsenic and then a compound of iron and arsenic which is of a light gray color and has the hexagonal form of arsenic. On heating it gives off a white sublimate of arsenic trioxide. If the sublimate is given up, the residue is a white sublimate of arsenic trioxide. If the sublimate is given up, the residue is a white sublimate of arsenic trioxide. If the sublimate is given up, the residue is a white sublimate of arsenic trioxide.

Diff. Crystals of arsenic have been found in the white arsenic, but they are not of the same character as those of arsenic. They are of a different character, being of a different color and having a different luster.

Obs. Arsenic is the most common metallic substance occurring in nature. It is widespread in the crust of the earth, being found in various localities. It is found in the form of native arsenic, in the form of arsenic compounds, and in the form of arsenic alloys. It is found in the form of native arsenic, in the form of arsenic compounds, and in the form of arsenic alloys.

Native arsenic has been found in various localities. It is found in the form of native arsenic, in the form of arsenic compounds, and in the form of arsenic alloys. It is found in the form of native arsenic, in the form of arsenic compounds, and in the form of arsenic alloys. It is found in the form of native arsenic, in the form of arsenic compounds, and in the form of arsenic alloys.

The name arsenic is of doubtful origin. It is derived from the Sanskrit word *arsenic*, which means 'to burn'.

Use. — An ore of arsenic.

Godmundite. Tetrahedral. $a:b:c = 1.000:0.707:1.414$. Crystals elongated along a . Color silver white to steel-gray. $H = 5.5-6$. Occurs in a variety of localities, with lead and iron ore at the same place.

Godmundite is named in honor of the late Dr. Godmund. It is found in the form of native arsenic, in the form of arsenic compounds, and in the form of arsenic alloys.

H_2AsS_4 , etc., and the meta-acids, H_2AsS_5 , etc.; but $H_2As_2S_7$, etc., and a series of others are included. The metals present as bases are chiefly copper, silver, lead, also zinc, mercury, iron, ruthenium, osmium, nickel, cobalt, in small amount. In view of the hypothetical character of many of the acids whose salts are here represented, there is a certain advantage, for the sake of comparison, in writing the composition after the dualistic method, $RS AsS_4$, $2HS AsS_5$, etc.

Many of the species of the sulphosalt group are rare and can be only briefly mentioned. Further, as many of them are intimately associated with other similar minerals and are frequently imperfectly crystallized, good analyses are often rare. Therefore the interpretation of the available data and the proper classification of many species present difficulties. Forunately several general studies of the group have been made recently, and these (especially those made by Wherry and Foshag and by Vesce) have been largely followed in the classification given below.

It should be further noted that many authors include as part of the sulphosalt group many of the species classified in this book as belonging to the intermediate division of the sulphides, interpreting their composition as sulpho-ferrites, etc. (see pp. 430-432).

A. Acidic Division $RS (As,Sb,Bi)_2S_7 = 1 : 3, 1 : 2, 2 : 3, 4 : 4 : 5$

Echbergite	$(Cu,Fe)_2S \cdot 3(Bi,Sb)_2S_7$	Chivante	$PbS \cdot 2Bi_2S_3$ or $2PbS \cdot 3Bi_2S_3$
Yrbante	$Tl_2S \cdot As_2S_5$	Gladite	$2PbS \cdot Cu_2S \cdot 5Bi_2S_3$
Livingstonite	$Hg_2S \cdot 2Sb_2S_3$	Rezbanyite	$3PbS \cdot Cu_2S \cdot 5Bi_2S_3$
Hltsmitte	$5(Cu,Fe)_2S \cdot 2As_2S_5 \cdot 7Bi_2S_3$		

B. Meta-Division $RS (As,Sb,Bi)_2S_7 = 1 : 1$

Trechmannite	$Ag_2S \cdot As_2S_5$	Rhombohedral
Platynite	$PbS \cdot Bi_2S_3$	Rhombohedral

Zinkenite Group. Orthorhombic

Zinkenite	$PbS \cdot Sb_2S_3$	Hutchinsonite	$PbS \cdot Tl, Ag_2S \cdot 2Sb_2S_3$
Andorite	$2PbS \cdot Ag_2S \cdot 4Sb_2S_3$	Chalcostibite	$Cu_2S \cdot Sb_2S_3$
Lindströmite	$2PbS \cdot Cu_2S \cdot 3Bi_2S_3$	Empiechte	$Cu_2S \cdot Bi_2S_3$

Miargyrite Group. Monoclinic

Miargyrite	$Ag_2S \cdot Sb_2S_3$	Sartorite	$PbS \cdot As_2S_5$
Saundersite	$Ag_2S \cdot As_2S_5$	Lorandite	$Tl_2S \cdot As_2S_5$
Matildite	$Ag_2S \cdot Bi_2S_3$	Galenobismuthite	$PbS \cdot Bi_2S_3$
Aramayonte	$Ag_2S \cdot Sb \cdot Bi_2S_3$	Berthierite	$FeS \cdot Si_2S_5$

C. Intermediate Division. $RS (As,Sb,Bi)_2S_7 = 5 : 4, 3 : 2, 2 : 1, 5 : 2$

Fulöpöpte	$2PbS \cdot 3As_2S_5$	Monoclinic
Plagionite	$5PbS \cdot 4Sb_2S_3$	Monoclinic
Bismuthoplacionite	$5PbS \cdot 4Bi_2S_3$	Orthorhombic?

Baumhauerite	$4\text{PbS } 3\text{As}_2\text{S}_3$	Monoclinic
Fizelyite	$5\text{PbS } \text{Ag}_2\text{S } 4\text{Sb}_2\text{S}_3$	Monoclinic
Ramdohrite	$3\text{PbS } \text{Ag}_2\text{S } 3\text{Sb}_2\text{S}_3$	
Heteromorphite	$7\text{PbS } 4\text{Sb}_2\text{S}_3$	Monoclinic
Rathite	$3\text{PbS } 2\text{As}_2\text{S}_3$	Orthorhombic
Schurmerite	$3(\text{Ag}, \text{Pb})\text{S } 2\text{Bi}_2\text{S}_3$	
Hammarite	$5\text{PbS } 3\text{Bi}_2\text{S}_3$	
Wittite	$5\text{PbS } 3\text{Bi}_2(\text{S}, \text{Se})_3$	Orthorhombic
Benjaminite	$(\text{Cu}, \text{Ag})_2\text{S } 2\text{PbS } 2\text{Bi}_2\text{S}_3$	
Klaprothite	$3\text{Cu}_2\text{S } 2\text{Bi}_2\text{S}_3$	Orthorhombic

Jamesonite Group. Monoclinic or Orthorhombic

Jamesonite	$2\text{PbS } \text{Sb}_2\text{S}_3$	Monoclinic
Dufrenoyite	$2\text{PbS } \text{As}_2\text{S}_3$	Monoclinic
Owyheeite	$8\text{PbS } 2\text{Ag}_2\text{S } 5\text{Sb}_2\text{S}_3$	Orthorhombic?
Cosalite	$2\text{PbS } \text{Bi}_2\text{S}_3$	Orthorhombic
Kobeillite	$2\text{PbS } (\text{Bi}, \text{Sb})_2\text{S}_3$	SCHRAPACHITE $\text{PbS } \text{Ag}_2\text{S } \text{Bi}_2\text{S}_3?$
Bertholite	$5\text{PbS } 9\text{Cu}_2\text{S } 7\text{Sb}_2\text{S}_3$	
Semseyite	$9\text{PbS } 4\text{Sb}_2\text{S}_3$	Monoclinic
Boulangerite	$5\text{PbS } 2\text{Sb}_2\text{S}_3$	Orthorhombic
Preeslebenite	$5 \text{ Pb, Ag, S } 2\text{Sb}_2\text{S}_3$	Monoclinic
Diaphorite	$5 \text{ Pb, Ag, S } 2\text{Sb}_2\text{S}_3$	Orthorhombic

D. Ortho- Division. $\text{RS}, (\text{As}, \text{Sb}, \text{Bi})_2\text{S}_3 = 3 : 1$

Bourmonite Group. Orthorhombic

Bourmonite	$2\text{PbS } (\text{Cu}, \text{S})\text{Sb}_2\text{S}_3$	Lillianite	$3\text{PbS } \text{Bi}_2\text{S}_3$
Seligmannite	$2\text{PbS } (\text{Cu}, \text{S})\text{As}_2\text{S}_3$	Wittichenite	$3(\text{Cu}, \text{S})\text{Bi}_2\text{S}_3$
Aikinite	$2\text{PbS } (\text{Cu}, \text{S})\text{Bi}_2\text{S}_3$		

Pyrrargyrite Group. Rhombohedral-hemimorphic

Pyrrargyrite	$3\text{Ag}_2\text{S } \text{Sb}_2\text{S}_3$	Proustite	$3\text{Ag}_2\text{S } \text{As}_2\text{S}_3$
Pyrostilpnite	$3\text{Ag}_2\text{S } \text{Sb}_2\text{S}_3$		Monoclinic
Samsonite	$2\text{Ag}_2\text{S } \text{MnS } \text{Sb}_2\text{S}_3$		Monoclinic
Xanthoconite	$3\text{Ag}_2\text{S } \text{As}_2\text{S}_3$		Monoclinic
Quadrinite	$3\text{Ag}_2\text{S } \text{As}_2\text{S}_3?$		
Guitermanite	$3\text{PbS } \text{As}_2\text{S}_3?$		
Stylopyrite	$3\text{Cu}_2\text{S } \text{Sb}_2\text{S}_3?$		Monoclinic
Falkenhaynite	$3(\text{S}, \text{Sb})\text{S}_2?$		
TAPALPITK	$3\text{Ag}_2(\text{S}, \text{Te})\text{Bi}_2\text{S}_3$		

Tetrahedrite Group. Isometric-tetrahedral

Tetrahedrite	$30\text{Cu}_2\text{S Sb}_2\text{S}_3$	Tennantite	$3\text{Cu}_2\text{S As}_2\text{S}_3$
E. Basic Division. RS As, Sb, Bi, S₂ = 4 1, 5 1, 6 1, 9 1, 12 : 1			
Lengenbachite	$6\text{PbS Ag}_2\text{S 2As}_2\text{S}_3$		Triclinic?
Meneghinite	$4\text{PbS Sb}_2\text{S}_3$		Orthorhombic
Jordanite	$4\text{PbS As}_2\text{S}_3$		Monoclinic
Goangarrizite	$4\text{PbS Bi}_2\text{S}_3$		Monoclinic?
Stephanite	$5\text{Ag}_2\text{S Sb}_2\text{S}_3$		Orthorhombic
Geocromite	$5\text{PbS Sb}_2\text{S}_3$		Orthorhombic
Goldfieldite	$5\text{Cu}_2\text{S Sb, As, Bi, S, Te ?}$		
Beegerite	$6\text{PbS Bi}_2\text{S}_3$		Isometric?

Polybasite Group. Monoclinic

Polybasite	$9\text{Ag}_2\text{S Sb}_2\text{S}_3$	Pearceite	$9\text{Ag}_2\text{S As}_2\text{S}_3$
Polyargyrite	$12\text{Ag}_2\text{S Sb}_2\text{S}_3$		Isometric
Ultrabazite	$28\text{PbS 11Ag}_2\text{S 3GeS}_2 2\text{Sb}_2\text{S}_3$		Orthorhombic

A. Acidic Division

Eichbergite — $\text{Cu Fe Sb As Bi Sb}_2\text{S}_3$. Color iron-gray. $\text{H} > 6$. $\text{G} = 5.38$. Known in a single specimen from the Eichberg, Schwarzwald Mts., Germany.

Vrbasite — $17\text{As}_2\text{S}_3 2\text{Sb}_2\text{S}_3$. Orthorhombic. $\text{H} = 5.5$. $\text{G} = 5.7$. Color gray-black to dark red at first, then blackish-red. Occurs in association with reneger and experimentally at 400°C . from an arsenic-sulfide mixture. Macled. in masses.

Livingstonite — $12\text{Sb}_2\text{S}_3 1\text{As}_2\text{S}_3$. Orthorhombic. Color iron-gray, streak red. $\text{H} = 4.5$. $\text{G} = 5.2$. From Georgia. $\text{P} = 1.5$. $\text{Z} = 2$. $\text{G} = 5.1$. From Mexico. $\text{H} = 5.5$. $\text{G} = 5.2$. $\text{Z} = 2$. $\text{G} = 5.1$. From Mexico.

Hastingsite — $16\text{PbS 2Sb}_2\text{S}_3 2\text{Bi}_2\text{S}_3$. Orthorhombic. Color gray-black. $\text{H} = 5.5$. $\text{G} = 5.5$. From the Hastings mine, New York.

Chlorite — $2\text{PbS 2H}_2\text{S 2Sb}_2\text{S}_3$. Rhombohedral. Color iron-gray. From Chiviso, Peru. Many specimens of this mineral from this locality showed it to be a mixture of iron chloride and various other minerals. (See also the comments on Valerianite.)

Glaucoite — $12\text{PbS 2Sb}_2\text{S}_3 2\text{Bi}_2\text{S}_3$. Rhombohedral. Color gray-black. $\text{H} = 5.5$. $\text{G} = 5.5$. From the Glauco mine, Peru. Many specimens of this mineral from this locality showed it to be a mixture of iron chloride and various other minerals. (See also the comments on Valerianite.)

Rebunite — $12\text{PbS 2Sb}_2\text{S}_3 2\text{Bi}_2\text{S}_3$. Rhombohedral. Color iron-gray. $\text{G} = 5.1$. $\text{G} = 5.1$. From Rebun mine, Peru. Many specimens of this mineral from this locality showed it to be a mixture of iron chloride and various other minerals. (See also the comments on Valerianite.)

B. Meta-Division. RS As₂S₃, RS Sb₂S₃, etc.

Treichmannite — $\text{Ag}_2\text{As}_2\text{S}_3$. Rhombohedral. Crystals massive with granular habit. Color, rhombic-prismatic cleavage. $\text{H} = 5.5$. $\text{G} = 5.5$. From the Treichmann mine, Peru. Many specimens of this mineral from this locality showed it to be a mixture of iron chloride and various other minerals. (See also the comments on Valerianite.)

from Felsöbánya (Barr Spine, Rattmann, Bohemia. In complex crystals from Ransdorf near Freiberg, Saxony. From Cour and Bouzou. From the Soudanite mine, Zaïre (now in the province of Kasai). From the Flint and Silver City districts in Idaho, and the Harzburg district, Saxony.

Selenite Ag_2SeO_3 . Monoclinic. Crystals resemble a flattened hexagonal pyramid. One perfect cleavage (100) is rational. $\text{Ax} = 0.60$, $\text{Z} = 0.40$, $\text{ax} = 0.60$, $\text{ay} = 0.37$, $\text{H} = 1.5$, 2 , $\text{C} = 1.6$. Color light red, changing to orange on exposure to light. Streak vermillion. From the Harzburg, $\text{Ax} = 0.60$, $\text{Z} = 0.40$.

Selenite Sb_2SeO_3 . PbS Ag_2SeO_3 . In smaller crystals than the arsenic selenite, but more abundant. $\text{Ax} = 0.60$, $\text{Z} = 0.40$, $\text{ax} = 0.60$, $\text{ay} = 0.37$, $\text{H} = 1.5$, 2 , $\text{C} = 1.6$. Color dark brown, gray, or green, changing to red on exposure to light. Streak vermillion. From the Harzburg, $\text{Ax} = 0.60$, $\text{Z} = 0.40$.

Lorandite Te_2S_2 . PbS Ag_2TeO_3 . Highly crystalline, similar to arsenic selenite. Crystals perfect, with distinct (100). $\text{Ax} = 0.60$, $\text{Z} = 0.40$, $\text{ax} = 0.60$, $\text{ay} = 0.37$, $\text{H} = 1.5$, 2 , $\text{C} = 1.6$. Color dark brown, gray, or green, changing to red on exposure to light. Streak vermillion. From the Harzburg, $\text{Ax} = 0.60$, $\text{Z} = 0.40$.

Medusite $\text{Ag}_2\text{H}_2\text{S}_2$. In massive, crystalline, typical C_2 = 60. Color gray. From the Medusite mine near Matsuyama, Prov. Iwate, Japan. Also near Nakai, Shikoku, Japan. Occurs in large, crystalline, typical C_2 = 60. Color gray.

Aramayonite $\text{Ag}_2\text{Sb}_2\text{S}_2$. Triclinic. Crystals small, typical. PbS $\text{Ag}_2\text{Sb}_2\text{S}_2$. In place of 1. From the Aramayon mine near Matsuyama, Prov. Iwate, Japan. Also near Nakai, Shikoku, Japan. Occurs in large, crystalline, typical C_2 = 60. Color gray.

Chocovite PbS $\text{Ag}_2\text{Sb}_2\text{S}_2$. Also with Ag_2Cu . Crystals small, typical. PbS $\text{Ag}_2\text{Sb}_2\text{S}_2$. In place of 1. From the Chocovite mine near Matsuyama, Prov. Iwate, Japan. Also near Nakai, Shikoku, Japan. Occurs in large, crystalline, typical C_2 = 60. Color gray.

Berthierite FeS_2 . In massive, granular, typical C_2 = 60. Color dark gray. From the Berthierite mine near Matsuyama, Prov. Iwate, Japan. Also near Nakai, Shikoku, Japan. Occurs in large, crystalline, typical C_2 = 60. Color gray.

Berthierite FeS_2 . In massive, granular, typical C_2 = 60. Color dark gray. From the Berthierite mine near Matsuyama, Prov. Iwate, Japan. Also near Nakai, Shikoku, Japan. Occurs in large, crystalline, typical C_2 = 60. Color gray.

C. Intermediate Division

Pillöppite PbS $\text{Ag}_2\text{Sb}_2\text{S}_2$. Monoclinic. Crystals small, usually, flattened or rhombic. From the Pillöppite mine near Matsuyama, Prov. Iwate, Japan. Also near Nakai, Shikoku, Japan. Occurs in large, crystalline, typical C_2 = 60. Color gray.

Plagioclase AlSi_3O_8 . PbS $\text{Ag}_2\text{Sb}_2\text{S}_2$. In massive, granular, typical C_2 = 60. Color dark gray. From the Plagioclase mine near Matsuyama, Prov. Iwate, Japan. Also near Nakai, Shikoku, Japan. Occurs in large, crystalline, typical C_2 = 60. Color gray.

Brucite $\text{Mg}(\text{OH})_2$. In massive, granular, typical C_2 = 60. Color white. From the Brucite mine near Matsuyama, Prov. Iwate, Japan. Also near Nakai, Shikoku, Japan. Occurs in large, crystalline, typical C_2 = 60. Color white.

most important localities for its occurrence are Army Idles near Komsa, Kancha-I or Kansa, and Kancha-II in Arunachal Pradesh in the Himalayas. It occurs in quantity at Sit. 1000 ft. at Dug, near an A. Leelan. At the antimony mines in Sevier Co., Arkansas, and at Silver Spring in Co. South Dakota.

The former one was a young male from Spring Branch, Bennett's Selous station and I believe also from the same area as the latter. It was very similar to the first one, but it had a white patch at the base of the tail and a white patch at the base of the wing.

4. A person who was shown to be probably a traitor was not a traitor. (100%)

[illegible][illegible][illegible]

Kobeltive 2008-10-26-ys, Fibron-partiated or granular inactive C₁-G3 (short)

[illegible]

Semseyite. FePS_4 481.7. For relations to diagenesis and heteromorphism see index
pigeonite. Monoclinic. In tabular crystals and in small elongation. Cleavage not easily
seen. $d_{100} = 1.4$ (black) $d_{010} = 3.5$. From Semseyite, Utah. Syn. Hemitene.
In the Huey Mine at Wolfberg. From Chile, Bolivia.

ROULANGERIE

Orthorhombic. Axes $a = 0.5527$, $b = 0.7478$. In prismatic or tabular crystals or crystalline plates; translucent. $d_{100} = 2.53$, $d_{010} = 2.76$. $H = 2.5-3$. $G = 5.7-6.3$. Luster metallic. Color gray. Streak gray. Often covered with yellow spots from oxidation. Opaque. Streak red-brown.

Comp. $31\frac{1}{2}\text{S} + 25\frac{1}{2}\text{As}_2\text{S}_3 = \text{Sulphur } 18.9, \text{ antimony } 25.7 \text{ least } 55.4 = 100.$

Buy *Shuttle up for Enterprise* p. 646.

[illegible]

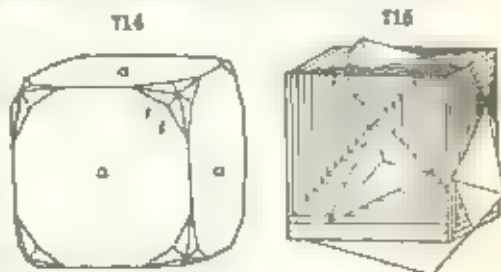
calcium atoms arranged on a face-centered cubic lattice with the fluorine atoms lying at the centers of the eight small cubes of which the unit cell is composed (see p. 41).

Cleavage: $\{111\}$ perfect. Fracture flat-conchoidal; of compact kinds, splintery. Brittle. $H = 4$. $G = 3.01-3.25$, 3.18 crystallized. Luster vit-



reous. Color white, yellow, green, rose and crimson-red, violet-blue, sky-blue, and brown, wine-yellow, greenish blue, violet-blue (most common), red (rare). Color often varies in different portions of the same specimen, showing bands of different shades which lie parallel to the cubic planes.

Further, the color may be modified by various means, such as heat, X-rays, radium rays, ultra-violet light, pressure, etc. Streak white. Transparent — subtranslucent. Sometimes shows a bluish fluorescence. (See p. 275.) Some deeply colored specimens appear blue by reflected light and green by transmitted light. Some varieties phosphoresce when heated (p. 275) and others when scratched with a knife blade. $n = 1.4349$. Often shows abnormal birefringence which varies in bands that lie parallel to the cubic planes. This is probably due to internal tension.



Comp. — Calcium fluoride, $\text{CaF}_2 = \text{Fluorine } 48.9$, calcium $51.1 = 100$. Old mine is sometimes present in minute quantities.

Var. 1. Ordinary — a cleavable or crystallized very various in colors. (b) fibrous or columnar, as the dark blue-blue-jade used for vases and other ornaments. It occurs in fine grains in the earth, (c), and sometimes very soft. Chlorophane yields a green phosphorescent light when heated.

Pyrite. In the form of cleavable and sometimes phosphorescent. It is in the form of a rhombicuboctahedron, which reacts alkaline on test paper. Fused in a closed tube with potassium bisulfate gives reaction for fluorine.

Def. Distinguished by its crystalline form, occasional cleavage (rarely without), its comparison with certain precious stones, also with the foliaceous etching power when treated with sulphuric acid. Does not effervesce with acid like calcite.

Obs. — Fluorite may be found in a very wide variety of conditions. It occurs most commonly as a very abundant mineral in deposits in which it is the chief constituent or as a gangue mineral with various metallic ores, especially those of iron, silver and zinc. It is also associated with quartz, rutile, zircon, etc. It is characteristic of certain basic igneous rocks, especially those carrying iron, and here is associated with hornblende, feldspar, biotite, apatite, etc. It is found in sedimentary rocks, as in dolomites and amonites. It is also found as a

brown on exposure due to oxidation. $n = 1.59$. Slightly soluble. Astringent taste. Found in Germany at Wolkramshausen near Nordhausen and elsewhere in Saxony and near Diepholz, Hanover.

CRYOLITE

Monoclinic. Axes $a : b : c = 0.9663 : 1 : 1.3882$, $\beta = 89^\circ 49'$.

$m\bar{m}$, $110 \wedge 1\bar{1}0 = 88^\circ 2'$
 m , $001 \wedge 1\bar{1}0 = 80^\circ 52'$
 c , $001 \wedge 111 = 55^\circ 2'$

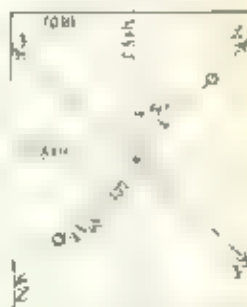
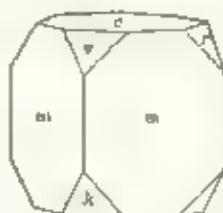
ck , $001 \wedge 101 = 55^\circ 17'$
 c , $001 \wedge 011 = 54^\circ 14'$
 cp , $001 \wedge 111 = 93^\circ 18'$

Crystals often cubic in aspect and grouped in parallel position, often with twin lamellae. Massive. The atomic structure has been shown to be similar to that of garnet. At about 570°C. changes to an isometric modification.

Parting at times due to twinning lamellae parallel to $c(001)$, $m(110)$ and $k(101)$. Fracture uneven. Brittle. $H. = 2.5$. $G. = 2.95\text{--}3.0$. Luster vitreous to greasy; somewhat pearly on $c(001)$. Colorless to snow-white, sometimes reddish or brownish to brick-red or even black. Transparent to translucent. Optically $+$. Ax. pl. \perp (010) . $Z \wedge c$ axis $= 44^\circ$. $2V = 43^\circ$. $n = 1.3385$. $\beta = 1.3380$, $\gamma = 1.3396$.

716

717



Comp. A fluoride of sodium and aluminum: Na_3AlF_6 or $3\text{NaF} \cdot \text{AlF}_3 =$ Fluorine 54.4, aluminum 12.8, sodium 32.8 = 100. A little iron sesquioxide is sometimes present as impurity.

Pyrr. etc. — Fuses in small fragments in the flame of a candle. Heated in C. T. with potassium sulphate gives fluorine reaction. In the furnace fuses very easily, color of the flame yellow. On heating fuses easily to a clear bead which, on cooling, becomes opaque; after long blow g , the mass spreads on the filament of wire in the furnace; the coal in the furnace of wire of fluorine is given off and a crust of aluminum fluoride, which, when treated with cold solution of HCl gives a blue color. Soluble in sulphuric acid with evolution of hydrofluoric acid.

Diff. Distinguished by its extreme brittleness. Because of its low index of refraction the powdered material becomes almost invisible when placed in water. Its planes of parting resembling cubic cleavage and softness are characteristic.

Obs. Occurs in a gray or black sand. West of Greenland at Ivigtut or Ivigtok, 1 mi. 1/2 from the beach, settlement of Ivigtut where it occurs on a large scale in a granitic vein in a gray gneiss. It is also an important part of the composition of the black sand of the coast of the North Sea. It is also found in the black sand of the coast of the North Sea. It is also found in the black sand of the coast of the North Sea.

Named from *color frid*, Latin, stone having meaning ice-stone, in allusion to the translucency of the white masses.

Use. In the manufacture of soda glass, certain kinds of glass and porcelain, and as a flux in the electrolytic process, in the production of aluminum.

Cryolithonate. $\text{NaF} \cdot 12\text{AlF}_3$, isomeric. In octahedral crystals. Has body-centered cubic structure, similar to that of garnet. Monoclinic crystals $n = 2.75$. $G. = 2.78$. Colorless or white. $n = 1.34$. Occurs associated with cryolite both at Ivigtut and in the Hume Mts.

Loranthite. — $6\text{PbO} \cdot \text{PbF}_2$. Tetragonal? Massive. Perfect basal cleavage. $G = 7.0$. $H = 3$. Fracture at right angles to cleavage with a 10° axial. Indices: $n_x = 1.5$, $n_y = 1.4$, $n_z = 1.4$. Loranthite, Texas. (Chapman, 1914). A reddish-brown tetragonal to orthorhombic of lead, 7140 (1914). From the same locality as the preceding, but with a different composition.

Hematophane. — $\text{Pb}_2\text{F}_2\text{O}_4$. Tetragonal. Lamellar aggregates of the parent. Microscopic cleavage parallel to base. $H = 2.5$. $G = 7.7$. Color dark red, with a greenish or gray. Streak red with red. Optically —. Occurs associated with plumbite in a lead ore, Bergslagen, Sweden.

Kemptite. $\text{MgO} \cdot 3\text{H}_2\text{O} \cdot 3\text{H}_2\text{O}$. Orthorhombic. In minute prismatic crystals. Color green. $G = 3.0$. $H = 2.5$. $G = 3.0$. Optically —. $n_x = 1.4$, $n_y = 1.4$, $n_z = 1.4$. Found very sparingly associated with carphosite in a large boulder of carphosite ore that formerly existed near the base of the Kemptite ore.

Dunbarite. An earthy mass with oxychloride of barium. From Cerro de Tama, Bol.

Nocerite. $\text{Ca}_2\text{Mg}_2\text{O}_4$. In white hexagonal nocerite to acicular crystals. Colorless to white, translucent. $G = 1.5$. $H = 1.5$. $G = 1.5$. Occurs in the same locality as the preceding, but with a different composition.

Kemperite. $\text{Ca}_2\text{Mg}_2\text{O}_4$. In white hexagonal nocerite to acicular crystals. Colorless to white, translucent. $G = 1.5$. $H = 1.5$. $G = 1.5$. Occurs in the same locality as the preceding, but with a different composition.

The following are the chlorides of mercury found in the mercury deposits at Tuziguan, Texas. A list of the names of the deposits is given in the preceding section.

Eggschite. Hg_2Cl_2 . In white to yellowish crystals. Colorless to white. $H = 2.5$. $G = 1.5$. $G = 1.5$. Occurs in the same locality as the preceding, but with a different composition.

Tetragonal. Hg_2Cl_2 . In white to yellowish crystals. Colorless to white. $H = 2.5$. $G = 1.5$. $G = 1.5$. Occurs in the same locality as the preceding, but with a different composition.

III Hydrous Chlorides, Hydrous Fluorides, etc.

CARNALLITE

Orthorhombic. Crystals rare. Commonly massive granular.

No cleavage. Fracture conchoidal. Brach. $H = 2.5$. $G = 1.6$. Taste salty, greasy. Color pink-white, often reddish. Transparent to translucent. Streak, phosphorescent. $n_x = 1.4$, $n_y = 1.4$, $n_z = 1.4$. $G = 1.4$. $H = 1.4$. $G = 1.4$. Axial angle $2\theta = 70^\circ$. Taste bitter. Deliquescent.

Comp. $\text{KMgCl}_2 \cdot 6\text{H}_2\text{O}$ or $\text{KMgCl}_2 \cdot 6\text{H}_2\text{O}$ = chloride 38.1, potassium 14.1, magnesium 8.7, water 39.1 = 100.

Obs. Carnallite is a common mineral in the same localities as the preceding. It is a white to yellowish mineral, often reddish. It is a white to yellowish mineral, often reddish. It is a white to yellowish mineral, often reddish.

Comp. $\text{KMgCl}_2 \cdot 6\text{H}_2\text{O}$ or $\text{KMgCl}_2 \cdot 6\text{H}_2\text{O}$ = chloride 38.1, potassium 14.1, magnesium 8.7, water 39.1 = 100.

Obs. Carnallite is a common mineral in the same localities as the preceding. It is a white to yellowish mineral, often reddish. It is a white to yellowish mineral, often reddish. It is a white to yellowish mineral, often reddish.

Comp. $\text{KMgCl}_2 \cdot 6\text{H}_2\text{O}$ or $\text{KMgCl}_2 \cdot 6\text{H}_2\text{O}$ = chloride 38.1, potassium 14.1, magnesium 8.7, water 39.1 = 100.

Obs. Carnallite is a common mineral in the same localities as the preceding. It is a white to yellowish mineral, often reddish. It is a white to yellowish mineral, often reddish. It is a white to yellowish mineral, often reddish.

Mischelichite $2\text{KClO}_4 \cdot 3\text{H}_2\text{O}$ Minute tetragonal crystals, greenish black color. $a = 1.61$, $b = 1.21$, $c = 2.18$. It is an anhydrous mineral from the crater of Vesuvius.

Tachyphite $\text{Fe}_2\text{Si}_2\text{O}_7 \cdot 2\text{H}_2\text{O}$ Rhombohedral, cleavage rhombohedral. $a = 1.15$, $b = 1.15$, $c = 1.15$. It is a mineral from the crater of Vesuvius.

Fluellite $\text{AlF}_3 \cdot 3\text{H}_2\text{O}$ Orthorhombic. In crystals or white pyramids. $H = 3$. $a = 1.473$, $b = 1.473$, $c = 1.473$. From the crater of Vesuvius.

Chloraluminite $\text{Al}_2\text{Si}_2\text{O}_7 \cdot 2\text{H}_2\text{O}$ Rhombohedral. Crystals, white, or yellowish. $H = 3$. $a = 1.15$, $b = 1.15$, $c = 1.15$.

Prosopite $\text{Ca}_2\text{Si}_2\text{O}_7 \cdot 2\text{H}_2\text{O}$ Rhombohedral. Crystals, white, or yellowish. $H = 3$. $a = 1.15$, $b = 1.15$, $c = 1.15$.

Pachynite $\text{Ca}_2\text{Si}_2\text{O}_7 \cdot 2\text{H}_2\text{O}$ Rhombohedral. Crystals, white, or yellowish. $H = 3$. $a = 1.15$, $b = 1.15$, $c = 1.15$.

Tachyphite $\text{Fe}_2\text{Si}_2\text{O}_7 \cdot 2\text{H}_2\text{O}$ Rhombohedral. Crystals, white, or yellowish. $H = 3$. $a = 1.15$, $b = 1.15$, $c = 1.15$.

Fluellite $\text{AlF}_3 \cdot 3\text{H}_2\text{O}$ Orthorhombic. Crystals, white, or yellowish. $H = 3$. $a = 1.473$, $b = 1.473$, $c = 1.473$.

Chloraluminite $\text{Al}_2\text{Si}_2\text{O}_7 \cdot 2\text{H}_2\text{O}$ Rhombohedral. Crystals, white, or yellowish. $H = 3$. $a = 1.15$, $b = 1.15$, $c = 1.15$.

Prosopite $\text{Ca}_2\text{Si}_2\text{O}_7 \cdot 2\text{H}_2\text{O}$ Rhombohedral. Crystals, white, or yellowish. $H = 3$. $a = 1.15$, $b = 1.15$, $c = 1.15$.

Pachynite $\text{Ca}_2\text{Si}_2\text{O}_7 \cdot 2\text{H}_2\text{O}$ Rhombohedral. Crystals, white, or yellowish. $H = 3$. $a = 1.15$, $b = 1.15$, $c = 1.15$.

Tachyphite $\text{Fe}_2\text{Si}_2\text{O}_7 \cdot 2\text{H}_2\text{O}$ Rhombohedral. Crystals, white, or yellowish. $H = 3$. $a = 1.15$, $b = 1.15$, $c = 1.15$.

Fluellite $\text{AlF}_3 \cdot 3\text{H}_2\text{O}$ Orthorhombic. Crystals, white, or yellowish. $H = 3$. $a = 1.473$, $b = 1.473$, $c = 1.473$.

Chloraluminite $\text{Al}_2\text{Si}_2\text{O}_7 \cdot 2\text{H}_2\text{O}$ Rhombohedral. Crystals, white, or yellowish. $H = 3$. $a = 1.15$, $b = 1.15$, $c = 1.15$.

Prosopite $\text{Ca}_2\text{Si}_2\text{O}_7 \cdot 2\text{H}_2\text{O}$ Rhombohedral. Crystals, white, or yellowish. $H = 3$. $a = 1.15$, $b = 1.15$, $c = 1.15$.

Pachynite $\text{Ca}_2\text{Si}_2\text{O}_7 \cdot 2\text{H}_2\text{O}$ Rhombohedral. Crystals, white, or yellowish. $H = 3$. $a = 1.15$, $b = 1.15$, $c = 1.15$.

Tachyphite $\text{Fe}_2\text{Si}_2\text{O}_7 \cdot 2\text{H}_2\text{O}$ Rhombohedral. Crystals, white, or yellowish. $H = 3$. $a = 1.15$, $b = 1.15$, $c = 1.15$.

V. OXIDES

I. Oxides of Silicon.

II. Oxides of the Semi-Metals, Tellurium, Arsenic, Antimony, Bismuth; also Molybdenum, Tungsten.

III. Oxides of the Metals.

The fifth class, that of the Oxides, is subdivided into three sections according to the positive element present. The oxides of the non-metals, which are placed by themselves, but it is to be noted that the compounds of the non-metals with hydrogen are related with those of the metals proper. It is to be noted that in our of its forms Fe_2O_3 is isomorphous with MnO_2 and PbO_2 .

A series of oxygen compounds which are properly to be viewed as salts, e.g., the species of the Spinel Group and a few others, are for convenience also included in this class.

I. Oxides of Silicon

QUARTZ.

Rhombohedral-trapezohedral Axis: $c = 1.00007$

$$rr', 10.1 \wedge \bar{1}101 = 85^\circ 46'$$

$$rr', 10\bar{1}1 \wedge 01\bar{1}1 = 16^\circ 10'$$

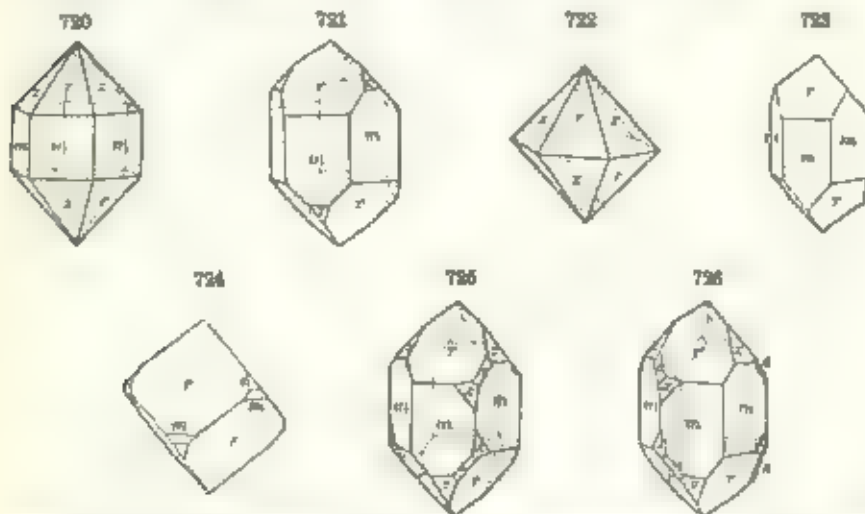
$$mr, 10\bar{1}0 \wedge 011 = 38^\circ 13'$$

$$mr, 10\bar{1}0 \wedge 01\bar{1}1 = 66^\circ 52'$$

$$mr, 10\bar{1}0 \wedge 1\bar{1}21 = 37^\circ 58'$$

$$mr, 10\bar{1}0 \wedge 51\bar{1}1 = 32^\circ 1'$$

Crystals commonly prismatic, with the $m(10\bar{1}0)$ faces horizontally striated, terminated commonly by the two rhombohedrons, $r(10\bar{1}1)$ and $z(01\bar{1}1)$, in nearly equal development, giving the appearance of a hexagonal, pyri-



mid; when one rhombohedron predominates it is in almost all cases r . Often in double six-sided pyramids or *quartzoids* through the equal development of r and z , when r is relatively large the form then has a cubic aspect ($rr' = 85^\circ 46'$). Crystals frequently distorted, when the correct orientation may be obscure except as shown by the striations on m . Crystals often elongated to acicular forms, and tapering through the oscillatory combination of successive rhombohedrons with the prism. Occasionally twisted or bent. Frequently in radiated masses with a surface of pyramids, or in druses. That quartz has a complicated atomic structure has been shown by X-ray study. The silicon atoms lie on three interpenetrating hexagonal lattices which have in the vertical direction a spiral arrangement in respect to each other. The oxygen atoms are apparently grouped in a tetrahedral manner about the silicon atoms. The unit cell contains three silicon atoms.

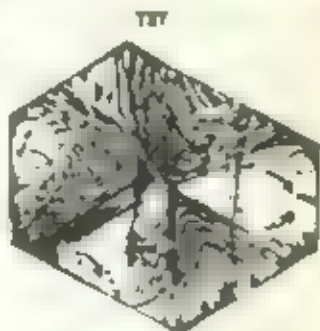
Quartz is enantiomorphic and simple crystals are either right- or left-handed. On a right-handed crystal (Fig. 726) the right trigonal pyramid $\pm 11\bar{2}1$, if present, lies to the right

[illegible]

with or without a will

Two: (1) two more specimens; (2) two plates mounted on the *Leptocarpus* which is one of the specimens. (p. 725) (1) two more specimens; (2) two plates mounted on the *Leptocarpus* which is one of the specimens. (p. 725) (1) two more specimens; (2) two plates mounted on the *Leptocarpus* which is one of the specimens. (p. 725)

284 The authors conclude that the observed surface fracture surfaces are [101] and [110] and that the [110] face is not growing after being heated, see Ar.

[illegible][illegible]

Plural correlation, "far and light"
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rt 402 p 295, and Fig. 727.
f page Refractive indices
n cavity power for search
electric, and electric by pro-

min. or pseudomorph. See Arts 450, 451. On etching-figures, see Arts 291, 292.

Comp. — silica, or silica dihydrate $SiH_4 =$ Oxygen 53.3, silicon 46.7 = 100

In nature it is found in a few places, but is very common in the laboratory.

Art. 450. — It is a very common mineral, and is found in many places. It is a very common mineral, and is found in many places.

Art. 451. — It is a very common mineral, and is found in many places. It is a very common mineral, and is found in many places.

It is a very common mineral, and is found in many places. It is a very common mineral, and is found in many places.

A. PHENOCRYSTALLINE OR VITREOUS VARIETIES

Chalcedony, *Opaloid*, or *Opaloid*, is a very common mineral, and is found in many places. It is a very common mineral, and is found in many places.

It is a very common mineral, and is found in many places. It is a very common mineral, and is found in many places.

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It is a very common mineral, and is found in many places. It is a very common mineral, and is found in many places.

B. CRYSTALLINE VARIETIES

Chalcedony — Having the same nearly of wh. and is transparent or translucent. It is a very common mineral, and is found in many places. It is a very common mineral, and is found in many places.

1. The first part of the report discusses the general situation of the country and the progress of the work. It also mentions the results of the work done in the past year.

La Nuova

[illegible]

and of full com-

glistening, subhyaline. Breaks
The tint of the chalk forma-

Ⓒ Besides the above there are also:

The first part of the document is a list of names and their corresponding addresses. The names are written in a cursive script, and the addresses are written in a more formal, printed script. The list is organized into two columns, with names on the left and addresses on the right.

The second part of the document is a list of names and their corresponding addresses, similar to the first part. The names are written in a cursive script, and the addresses are written in a more formal, printed script. The list is organized into two columns, with names on the left and addresses on the right.

The third part of the document is a list of names and their corresponding addresses, similar to the first two parts. The names are written in a cursive script, and the addresses are written in a more formal, printed script. The list is organized into two columns, with names on the left and addresses on the right.

The fourth part of the document is a list of names and their corresponding addresses, similar to the first three parts. The names are written in a cursive script, and the addresses are written in a more formal, printed script. The list is organized into two columns, with names on the left and addresses on the right.

The fifth part of the document is a list of names and their corresponding addresses, similar to the first four parts. The names are written in a cursive script, and the addresses are written in a more formal, printed script. The list is organized into two columns, with names on the left and addresses on the right.

The sixth part of the document is a list of names and their corresponding addresses, similar to the first five parts. The names are written in a cursive script, and the addresses are written in a more formal, printed script. The list is organized into two columns, with names on the left and addresses on the right.

The seventh part of the document is a list of names and their corresponding addresses, similar to the first six parts. The names are written in a cursive script, and the addresses are written in a more formal, printed script. The list is organized into two columns, with names on the left and addresses on the right.

The eighth part of the document is a list of names and their corresponding addresses, similar to the first seven parts. The names are written in a cursive script, and the addresses are written in a more formal, printed script. The list is organized into two columns, with names on the left and addresses on the right.

The ninth part of the document is a list of names and their corresponding addresses, similar to the first eight parts. The names are written in a cursive script, and the addresses are written in a more formal, printed script. The list is organized into two columns, with names on the left and addresses on the right.

The tenth part of the document is a list of names and their corresponding addresses, similar to the first nine parts. The names are written in a cursive script, and the addresses are written in a more formal, printed script. The list is organized into two columns, with names on the left and addresses on the right.

[illegible]

hydrofluoric acid. When used

[illegible]

1. The first part of the document is a list of names and addresses, which appears to be a directory or a list of contacts. The names are written in a cursive script, and the addresses are listed below them.

1708

1. The first part of the document is a list of references. The references are listed in a standard format, including the author's name, the title of the work, and the publisher. The references are as follows:

1. J. H. Van Veen, *The History of the Netherlands*, 1910, 1911, 1912, 1913, 1914, 1915, 1916, 1917, 1918, 1919, 1920, 1921, 1922, 1923, 1924, 1925, 1926, 1927, 1928, 1929, 1930, 1931, 1932, 1933, 1934, 1935, 1936, 1937, 1938, 1939, 1940, 1941, 1942, 1943, 1944, 1945, 1946, 1947, 1948, 1949, 1950, 1951, 1952, 1953, 1954, 1955, 1956, 1957, 1958, 1959, 1960, 1961, 1962, 1963, 1964, 1965, 1966, 1967, 1968, 1969, 1970, 1971, 1972, 1973, 1974, 1975, 1976, 1977, 1978, 1979, 1980, 1981, 1982, 1983, 1984, 1985, 1986, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020, 2021, 2022, 2023, 2024, 2025, 2026, 2027, 2028, 2029, 2030, 2031, 2032, 2033, 2034, 2035, 2036, 2037, 2038, 2039, 2040, 2041, 2042, 2043, 2044, 2045, 2046, 2047, 2048, 2049, 2050, 2051, 2052, 2053, 2054, 2055, 2056, 2057, 2058, 2059, 2060, 2061, 2062, 2063, 2064, 2065, 2066, 2067, 2068, 2069, 2070, 2071, 2072, 2073, 2074, 2075, 2076, 2077, 2078, 2079, 2080, 2081, 2082, 2083, 2084, 2085, 2086, 2087, 2088, 2089, 2090, 2091, 2092, 2093, 2094, 2095, 2096, 2097, 2098, 2099, 2100, 2101, 2102, 2103, 2104, 2105, 2106, 2107, 2108, 2109, 2110, 2111, 2112, 2113, 2114, 2115, 2116, 2117, 2118, 2119, 2120, 2121, 2122, 2123, 2124, 2125, 2126, 2127, 2128, 2129, 2130, 2131, 2132, 2133, 2134, 2135, 2136, 2137, 2138, 2139, 2140, 2141, 2142, 2143, 2144, 2145, 2146, 2147, 2148, 2149, 2150, 2151, 2152, 2153, 2154, 2155, 2156, 2157, 2158, 2159, 2160, 2161, 2162, 2163, 2164, 2165, 2166, 2167, 2168, 2169, 2170, 2171, 2172, 2173, 2174, 2175, 2176, 2177, 2178, 2179, 2180, 2181, 2182, 2183, 2184, 2185, 2186, 2187, 2188, 2189, 2190, 2191, 2192, 2193, 2194, 2195, 2196, 2197, 2198, 2199, 2200, 2201, 2202, 2203, 2204, 2205, 2206, 2207, 2208, 2209, 2210, 2211, 2212, 2213, 2214, 2215, 2216, 2217, 2218, 2219, 2220, 2221, 2222, 2223, 2224, 2225, 2226, 2227, 2228, 2229, 2230, 2231, 2232, 2233, 2234, 2235, 2236, 2237, 2238, 2239, 2240, 2241, 2242, 2243, 2244, 2245, 2246, 2247, 2248, 2249, 2250, 2251, 2252, 2253, 2254, 2255, 2256, 2257, 2258, 2259, 2260, 2261, 2262, 2263, 2264, 2265, 2266, 2267, 2268, 2269, 2270, 2271, 2272, 2273, 2274, 2275, 2276, 2277, 2278, 2279, 2280, 2281, 2282, 2283, 2284, 2285, 2286, 2287, 2288, 2289, 2290, 2291, 2292, 2293, 2294, 2295, 2296, 2297, 2298, 2299, 2300, 2301, 2302, 2303, 2304, 2305, 2306, 2307, 2308, 2309, 2310, 2311, 2312, 2313, 2314, 2315, 2316, 2317, 2318, 2319, 2320, 2321, 2322, 2323, 2324, 2325, 2326, 2327, 2328, 2329, 2330, 2331, 2332, 2333, 2334, 2335, 2336, 2337, 2338, 2339, 2340, 2341, 2342, 2343, 2344, 2345, 2346, 2347, 2348, 2349, 2350, 2351, 2352, 2353, 2354, 2355, 2356, 2357, 2358, 2359, 2360, 2361, 2362, 2363, 2364, 2365, 2366, 2367, 2368, 2369, 2370, 2371, 2372, 2373, 2374, 2375, 2376, 2377, 2378, 2379, 2380, 2381, 2382, 2383, 2384, 2385, 2386, 2387, 2388, 2389, 2390, 2391, 2392, 2393, 2394, 2395, 2396, 2397, 2398, 2399, 2400, 2401, 2402, 2403, 2404, 2405, 2406, 2407, 2408, 2409, 2410, 2411, 2412, 2413, 2414, 2415, 2416, 2417, 2418, 2419, 2420, 2421, 2422, 2423, 2424, 2425, 2426, 2427, 2428, 2429, 2430, 2431, 2432, 2433, 2434, 2435, 2436, 2437, 2438, 2439, 2440, 2441, 2442, 2443, 2444, 2445, 2446, 2447, 2448, 2449, 2450, 2451, 2452, 2453, 2454, 2455, 2456, 2457, 2458, 2459, 2460, 2461, 2462, 2463, 2464, 2465, 2466, 2467, 2468, 2469, 2470, 2471, 2472, 2473, 2474, 2475, 2476, 2477, 2478, 2479, 2480, 2481, 2482, 2483, 2484, 2485, 2486, 2487, 2488, 2489, 2490, 2491, 2492, 2493, 2494, 2495, 2496, 2497, 2498, 2499, 2500, 2501, 2502, 2503, 2504, 2505, 2506, 2507, 2508, 2509, 2510, 2511, 2512, 2513, 2514, 2515, 2516, 2517, 2518, 2519, 2520, 2521, 2522, 2523, 2524, 2525, 2526, 2527, 2528, 2529, 2530, 2531, 2532, 2533, 2534, 2535, 2536, 2537, 2538, 2539, 2540, 2541, 2542, 2543, 2544, 2545, 2546, 2547, 2548, 2549, 2550, 2551, 2552, 2553, 2554, 2555, 2556, 2557, 2558, 2559, 2560, 2561, 2562, 2563, 2564, 2565, 2566, 2567, 2568, 2569, 2570, 2571, 2572, 2573, 2574, 2575, 2576, 2577, 2578,

in rocket at in an essential sign

Figure 1. The effect of the number of trials on the number of correct responses. The number of correct responses was significantly higher for the 10 trials condition than for the 5 trials condition. Error bars represent the standard error of the mean.

quartz grains in a fragmental sand.

[Faint handwritten notes, mostly illegible]

1. *Phragmites australis* (Cav.) Trin. ex Steud.

Banffshire, Scot.

and Maria Gerack, Brazil, and

1. The first step is to identify the problem or question that needs to be answered. This involves understanding the context and the specific requirements of the task.

1. *Phragmites* (common)
2. *Phragmites* (common)
3. *Phragmites* (common)
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5. *Phragmites* (common)
6. *Phragmites* (common)
7. *Phragmites* (common)
8. *Phragmites* (common)
9. *Phragmites* (common)
10. *Phragmites* (common)

I am glad to hear that you are well.

smoky quartz come from the granite of the Pike's Peak region in Colorado. Chalcedony occurs at Rio Grande, Colorado. In Missouri, quartz points from near Hannibal to Frankfort, and is a quartzite in the St. Francois mts. Jefferson Co. Amethyst occurs in a few Yellow Springs Park, Wisconsin. Fine amethyst also occurs in the Thunder Bay district, Ontario, Canada.

The most important source of natural agate is from the river banks of the Rio Grande, New Mexico, where it is found in the form of nodules.

Use of quartz in the form of fused quartz as a material for making lenses, mirrors, etc., is of great importance. It is also used in the form of sandstone, etc., for making roads, etc., and as an acid in certain chemical operations.

TRIDYMITES.

Hexagonal or pseudo-hexagonal. $A_{100} = 1.6530$. Crystals usually minute, thin tabular (~ 0001), often in twinned also uniaxial in thin-stained groups.

Colorless, prismatic and distinct, parting γ , sometimes beveled. Fracture conchoidal. Birefringent. $H = 7$. $G = 2.28-2.43$. Luster vitreous, on cleavage surfaces to white. Transparent. Optically +. Indices, 1.469-1.473. Often exhibits optical phenomena in refraction phenomena.

Comp. Tridymite, SiO_2 , like quartz.

Tridymite is a polymorph of SiO_2 . See further under quartz p. 471. There are two forms of tridymite, one which is the stable form at low temperatures, and the other which is the stable form at high temperatures. The transition between the two forms is closely related to the pressure and temperature conditions, and is the result of X-ray study.

Pyrite, etc. have been found in association with tridymite.

Obs. In the form of small, thin, tabular crystals, often in twinned groups. The crystals are usually colorless, but may be smoky or brownish. They are transparent, and have a vitreous luster. The crystals are often found in association with quartz, and may be found in the form of small, thin, tabular crystals, often in twinned groups. The crystals are usually colorless, but may be smoky or brownish. They are transparent, and have a vitreous luster. The crystals are often found in association with quartz, and may be found in the form of small, thin, tabular crystals, often in twinned groups.

Notable examples of tridymite are found in the volcanic sequences of the Rio Grande, New Mexico, and in the form of small, thin, tabular crystals, often in twinned groups.

A-morphous. In the form of small, thin, tabular crystals, often in twinned groups. The crystals are usually colorless, but may be smoky or brownish. They are transparent, and have a vitreous luster. The crystals are often found in association with quartz, and may be found in the form of small, thin, tabular crystals, often in twinned groups.

Crystalline. In the form of small, thin, tabular crystals, often in twinned groups. The crystals are usually colorless, but may be smoky or brownish. They are transparent, and have a vitreous luster. The crystals are often found in association with quartz, and may be found in the form of small, thin, tabular crystals, often in twinned groups. The crystals are usually colorless, but may be smoky or brownish. They are transparent, and have a vitreous luster. The crystals are often found in association with quartz, and may be found in the form of small, thin, tabular crystals, often in twinned groups.

Melanophloids. In minute cubes, as in the form of small, thin, tabular crystals, often in twinned groups. The crystals are usually colorless, but may be smoky or brownish. They are transparent, and have a vitreous luster. The crystals are often found in association with quartz, and may be found in the form of small, thin, tabular crystals, often in twinned groups.

OPAL.

Aqueous solution. Massive, sometimes small, uniform, stalactitic or conchoidal. Frequently perfect in form, after other minerals. Amorphous.

Conchoidal fracture. $H = 5.5-6.5$. $G = 1.9-2.3$ when pure 2.1-2.2.

luster vitreous, frequently subvitreous, often inclining to resinous, and sometimes to pearly. Color white, yellow, red, brown, green, gray, and generally pale. Dark colors arise from foreign admixture, such as iron, or a rich assemblage of colors or different colors by refraction and reflection. Streak white. Translucent to nearly opaque. $n = 1.43$

[illegible]

Comp. Silica, like quartz with a varying amount of water $\text{SiO}_2 \cdot x\text{H}_2\text{O}$. The percentage of water is usually small with a maximum about 10 per cent.

The report contains information of the highest of intelligence and is of great value to the Government of the United States. It is a most valuable source of information and is of great value to the Government of the United States. It is a most valuable source of information and is of great value to the Government of the United States. It is a most valuable source of information and is of great value to the Government of the United States.

...and the... with fine reflections, somewhat

...with the
... ..
... ..
... ..
... ..
... ..

In concretionary forms; opaque, dull gray.

[illegible][illegible]

more formal system concerning my business about the govern. I the 14th and 15th
have I sent it to you for your review. I am not sure if it is
the same, consequently the form of your report. I am not sure if it is
the same.

11. Light gray and calcareous, smooth while at growth. Surface more
covered, rough in fracture.

[illegible]

Pre etc yellow water 1 b

The liquid is a non-crystalline colloidal substance belonging to the group of the
viscoelastic liquids. It has the properties $\eta = 10^{-1}$ poise, $\rho = 1.2$ g/cm³, $\alpha = 0.01$ cm²/sec.
Changes in composition with alkali metal, alkyl halides, and other substances.

Hematite Group. R_2O_3 Rhombohedral

		c
Corundum	Al_2O_3	1.3630
Hematite	Fe_2O_3	1.3656
Ilmenite	$(Fe, Mg)O \cdot TiO_2$ Tri-rhombohedral	1.3816
Senarite	$(Fe, Mn, Pb)O \cdot TiO_2$	1.385
Pyrophanite	$MnO \cdot TiO_2$	1.5092
Geikielite	$MgO \cdot TiO_2$	1.370

The HEMATITE GROUP embraces the sesquioxides of aluminum and iron. These compounds crystallize in the rhombohedral class, hexagonal system, with a fundamental rhombohedron differing but little in angle from a cube. Both the minerals belonging here—Hematite and Corundum—are hard.

To these species the titanates of iron, magnesium, and manganese—Ilmenite, Senarite, Pyrophanite, and Geikielite—are closely related in form though belonging to the tri-rhombohedral class (phenacite type), and in atomic structure. It is to be noted further, that hematite often contains titanium, and a titaniferous iron oxyphosphate compound, Fe_2O_3 , has been described. Hence the ground for writing the formula of ilmenite $(Fe, Ti)O_2$, as is done by some authors. It is shown by Penfield, however, that the formula $(Fe, Mg)O_2$ is more correct. For other titanates see p. 488.

CORUNDUM

Rhombohedral Axis $c = 1.3630$.

cr	$0001 \wedge 10\bar{1}1 = 57^\circ 34'$	mn'	$2243 \wedge 3423 = 51^\circ 55'$
ch	$0001 \wedge 2243 = 61^\circ 11'$	nn'	$4488 \wedge 4843 = 67^\circ 38'$
rr'	$10\bar{1}1 \wedge 1101 = 93^\circ 56'$	zz	$2441 \wedge 2421 = 85^\circ 55'$

Twins tw pl $r(10\bar{1}1)$ sometimes penetration-twins, often polysynthetic and thus producing a laminated structure. Crystals usually rough and rounded. Also massive, with nearly rectangular parting or pseudo-scleavage.

729



730



731



732



granular, coarse or fine. X-ray study shows a compacted atomic structure. The structure can be likened to a deformed haidite structure in which the two different atoms are replaced by equiaxial Al_2O_3 groups.

Parting $r(0001)$ sometimes perfect, but interrupted, also $r(10\bar{1}1)$, due to twinning, often prominent, a $11\bar{2}0$ less distinct. Fracture uneven to conchoidal. Brittle, when compact very tough. $H = 9$. $G = 32$. Luster laminae to vitreous, lc sometimes pearly. Occasionally showing asterism. Color blue, red, yellow, brown, gray, and nearly white, streak

unclouded. Dichroic in deeply colored varieties. Transparent to translucent. Normal optical negative for sapphire $\omega = 1.7676$ to 1.7682 and $\epsilon = 1.7594$ to 1.7598 (often at normal maxima).

Var. There are three well-known varieties of the gemstone practically recognized in the arts. 1. *Colorless*. 2. *Deep blue*. 3. *Red*. The colorless variety is transparent to translucent when all gemstone surfaces are polished as in the case of the other two. The deep blue variety is translucent when the surfaces are polished, but becomes transparent when the surfaces are ground and polished. The red variety is translucent when the surfaces are polished, but becomes transparent when the surfaces are ground and polished.

Crystallization. In the case of the colorless variety and the deep blue variety, the crystals are usually small and are often found in the form of thin plates. The red variety is usually found in the form of small, rounded, or irregular crystals. The crystals of the colorless variety are usually found in the form of thin plates, and the crystals of the deep blue variety are usually found in the form of thin plates. The crystals of the red variety are usually found in the form of small, rounded, or irregular crystals.

Comp. — Alumina, $\text{Al}_2\text{O}_3 = 47.1$, aluminum 52.9 = 100. The crystals of the colorless variety are usually pure, containing only a little ferric oxide as an impurity. The crystals of the deep blue variety are perhaps due to the presence of varying amounts of ferric oxide, and the crystals of the red variety are due to the presence of varying amounts of ferric oxide. The crystals of the colorless variety are usually pure, containing only a little ferric oxide as an impurity. The crystals of the deep blue variety are perhaps due to the presence of varying amounts of ferric oxide, and the crystals of the red variety are due to the presence of varying amounts of ferric oxide.

Artificial. The colorless variety is usually found in the form of thin plates, and the crystals of the deep blue variety are usually found in the form of thin plates. The crystals of the red variety are usually found in the form of small, rounded, or irregular crystals. The crystals of the colorless variety are usually found in the form of thin plates, and the crystals of the deep blue variety are usually found in the form of thin plates. The crystals of the red variety are usually found in the form of small, rounded, or irregular crystals.

Pyro. The colorless variety is usually found in the form of thin plates, and the crystals of the deep blue variety are usually found in the form of thin plates. The crystals of the red variety are usually found in the form of small, rounded, or irregular crystals. The crystals of the colorless variety are usually found in the form of thin plates, and the crystals of the deep blue variety are usually found in the form of thin plates. The crystals of the red variety are usually found in the form of small, rounded, or irregular crystals.

Micro. In the case of the colorless variety, the crystals are usually small and are often found in the form of thin plates. The crystals of the deep blue variety are usually found in the form of thin plates, and the crystals of the red variety are usually found in the form of small, rounded, or irregular crystals.

Obs. The colorless variety is usually found in the form of thin plates, and the crystals of the deep blue variety are usually found in the form of thin plates. The crystals of the red variety are usually found in the form of small, rounded, or irregular crystals.

Alloys. In the case of the colorless variety, the crystals are usually small and are often found in the form of thin plates. The crystals of the deep blue variety are usually found in the form of thin plates, and the crystals of the red variety are usually found in the form of small, rounded, or irregular crystals.

Alloys. In the case of the colorless variety, the crystals are usually small and are often found in the form of thin plates. The crystals of the deep blue variety are usually found in the form of thin plates, and the crystals of the red variety are usually found in the form of small, rounded, or irregular crystals. The crystals of the colorless variety are usually found in the form of thin plates, and the crystals of the deep blue variety are usually found in the form of thin plates. The crystals of the red variety are usually found in the form of small, rounded, or irregular crystals.

masses, accompanied by grains of magnetite, and several kinds of gems, as spinel, etc. The emery of Asia Minor occurs in granular limestone.

The best rubies come from the mines in Upper Burma, north of Mandalay, in an area covering 25 to 30 square miles, of which Mogoke is the center. The rubies occur in situ in crystalline limestone, also in the w of the limestones and in gem-bearing gravels of the Irrawaddy River. Blue sapphires as well as stones of many other colors are brought from Ceylon from the Ratnapura and Badulla districts, often as rough stones, also as well-preserved crystals. Fine blue sapphires and also rubies from the mountains of Burmah near Bhamo are in Lapis lazuli and Chantabon in Siam. These stones come from various parts of India and also large coarse crystals in the Carnatic district of southern Madras, also in Coimbatore and Mysore. Sapphires and pure blue opaque crystals come from Kashmir, northern India. Prismatic or tabular crystals from gray to blackish blue from Takayama, Mino, Japan. From the Kuroki Mts. at Zintast and Musak. In Tiemo, Switzerland, at Champoung near St. Gotthard with a red or blue tinge a selenite. In large opaque crystals and masses from various places in Manchuria, particularly in Siberia, at Ustondnogy and elsewhere southeast of Amur, also in crystals and refined pieces of gem quality in many deposits. Large opaque crystals are found at St. Petersburg and in the Cape Province, South Africa, and in the Zoutpansberg and Pietersburg districts, Transvaal.

In the United States corundum occurs in Orange Co., New York, at Warwick, hunch and pink with spinel and at Amity white blue roiled crystals. In Sussex Co., New Jersey, at Franklin Furnace, at Newton in blue crystals, at Verona in red crystals, at Sparta, etc. In Pennsylvania, in Chester Co., at Conowing 1011 near Newlin township, was abundant in crystals and large masses, also in Delaware Co., in Arton township in large crystals, also in Lehigh Co., at Shomerville. In California at many places along a belt extending from Virginia across western North and South Carolina and Georgia to Dadeville, Alabama. The localities at which most mining was done were Corns in the hills near Franklin, Macon Co., North Carolina, and southeast at Laurel Creek, Georgia. Clear sapphires are found near Hele, a Montana, in gold workings up in one of the Yellowstone River, especially the Horsehide Bar at Big Creek on the Yellowstone where they also occur in an undecomposed state at other localities. In Ontario corundum occurs in many places in greenish and blackish in the south-central and eastern counties, especially in Hastings Co. in red and blue crystals at South Burgess in Leeds Co., and in many places in Renfrew Co.

Emerald is found in the island of Naxos and elsewhere in the Cyclades, Greece, also in Asia Minor east of Ephesus in the mountains of Cilicia Dagli Mesoria and in various districts north of Smyrna. In Massachusetts, at Chester corundum and emery occur in a large vein.

Use. Clear varieties of corundum form valuable gem stones as noted above. Also formerly largely used as an abrasive, at present various artificial abrasives are mostly used instead.

HEMATITE.

Rhombohedral. Axis $c = 1.3658$.

$$\begin{aligned} \sigma, 0001 \wedge 1011 &= 57^\circ 37' \\ \pi, 1011 \wedge 1101 &= 84^\circ 0' \\ dd, 0112 \wedge 1112 &= 84^\circ 51' \end{aligned}$$

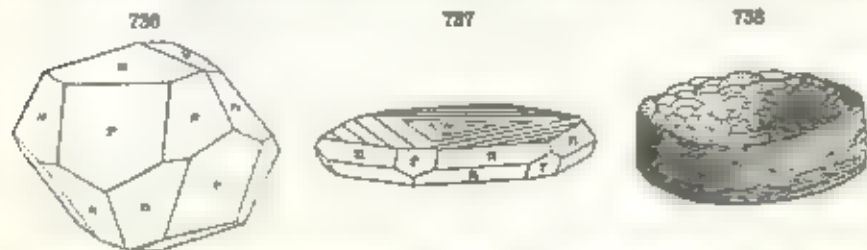
$$\begin{aligned} uv, 1011 \wedge 1104 &= 37^\circ 3' \\ uv, 2211 \wedge 2121 &= 51^\circ 50' \\ \sigma, 0001 \wedge 2243 &= 61^\circ 13' \end{aligned}$$

Twins: (w pl) (1) $\{0001\}$, penetration-twins (2) $\{0112\}$, less common, usually as polysynthetic twinning lamellae, producing a fine striation on $\{0001\}$ and giving rise to a distinct parting or pseudo-chlamysis $\parallel \{1011\}$. Crystals often thick to thin tabular c , and grouped in parallel position or in rosettes, c faces striated edge $c \wedge \{0112\}$ and other forms due to secondary combination, also in cube-like rhombohedrons, rhombohedra, faces $h\{1011\}$ horizontally striated and often rounded over in convex forms. Also columnar to granu-



lar botryoidal, and stalactate shapes, also lamellar, laminae joined parallel to *c*, and variously bent, thick or thin, also granular, friable, earthy or compact.

Parting $\epsilon(0001)$ due to lamellar structure, also $\gamma(10\bar{1}1)$, caused by twinning. Fracture subconchoidal to uneven. Brittle in compact forms, elastic



in thin laminae, soft and malleable in some loosely adherent sandy varieties. $H = 5.5-6.5$, $G = 4.9-5.3$, of crystals mostly 5.20-5.25, of some compact varieties, as low as 4.2. Luster metallic and occasionally sparsely crystalline. Color dark steel-gray or iron-black, in very thin particles blood-red, by transmitted light, when earthy red. Streak cherry-red or reddish brown. Opaque, except when in very thin laminae.

Var 1 Specular. Luster metallic, and crystals often splendid, when the mass appears thin. When the surface is polished it increases, because the surface is then more regular. The numerous varieties are soft and malleable. Some varieties are magnetic, or at least strongly attracted to a magnet. See Arts 453-455.

2 Compact Columnar or Fibrous. The masses often are branching, and are sometimes metallic, sometimes dark red or iron-black. Some masses are very hard, and are not easily scratched. See Arts 453-455.

3 Earthy or Sandy. Red and earthy. Ruddle and red chalk are red, and mixed with lime or silica.

4 Crystalline. *Anglesonite hematite.* Hard, brownish black, or reddish brown, often in small crystals. It consists of oxide of iron with clay or sand, and sometimes other impurities.

Comp. — Iron sesquioxide $Fe_2O_3 =$ Oxygen 30 iron 70 = 100. Sometimes contains titanium and magnesium, and is thus closely related to ilmenite, p. 486.

Pyr., etc. It is infusible in charcoal in RF, becomes magnetic with strong gases in RF, and in RF. With iron in charcoal in RF it remains black, and magnetic powder is obtained in RF.

Diff. It is distinguished from magnetite by its red streak, from rhombic by the same means, and from the carbonates by being water from carbonates by being insoluble in water. It is distinguished from ilmenite by being insoluble in water, and from hematite by being insoluble in water.

Artif. Crystals of hematite have been made by the following method: by steam at high temperature, also by the action of heated air on iron, and by reduction of iron from FeO . It has been crystallized from various artificial magmas, which must contain at least some ferrous iron.

Obs. Hematite is formed in various ways and is found in rocks of all ages. It occurs in connection with volcanic activities as a by-product, usually as earthy thin crystals, plates, or small grains. It is primarily a product of the action of water vapor upon iron. Hematite is found also as a constituent of igneous rocks but not where the original magma was or became ferruginous. It is also a product of the oxidation of the greenish iron ore, hematite, etc. At times it is a product of the oxidation, occurring in granites or pegmatites. It also occurs in the metamorphic rocks, as, for instance,

ILMENITE or MENEGANTITE. Titanic Iron Ore.

Trirhombohedral, Axis $c = 1.3816$.

or, $\sin A \approx 10^{-1} = 57^\circ 53'$.

$$F_{1011} = 1.01 = 94.5\%$$

$$\sigma_{\theta} = 0.001 \text{ A } 2243 = 81^{\circ} 38'$$

Crystals usually thick tabular, also acute rhombohedral. Often in thin plates or laminae. Massive, compact, in embedded grains, also loose as sand.



The atomic structure is similar to that of corundum, providing one-half of the lattice Al atoms be replaced by Fe and the other half by Ti.

Fracture conchoidal H.
= 5-6. G = 4.5-5. Luster submetallic. Color iron-

black. Streak submetallic powder black to brownish red. Opaque. Infus-
ences slightly frothy, effervescent.

Comp.—If normal, FeTiO_3 or $\text{FeO} \cdot \text{TiO}_2 = \text{Oxygen } 31.6, \text{ titanium } 31.6, \text{ iron } 40.8 = 100$. Sometimes written $(\text{Fe}, \text{Ti})\text{O}_3$, but probably to be regarded as an iron titanate. Sometimes also contains magnesium (*peradumite*), replacing the ferrous iron, hence the general formula $(\text{Fe}, \text{Mg}) \cdot \text{TiO}_3$ (Pentfield, *Chambers's gazetteer*, p. 487). The variations in composition shown by an assemblage are in part, at least, explained by the fact that specimens often show a regular intergrowth with, or have, a hematite or magnetite, in a manner analogous to the perthitic intergrowth of the feldspars.

[illegible]

Def. 1. See also Def. 1.1, but has no smaller, simply sub, strong not magnetic

[illegible][illegible][illegible]

early - found in the diamond-bearing series of Diamantina, Minas Gerais, Brazil.

Pyrophanite. Manganese titanate, $MnTiO_3$. In thin tabular rhombohedral crystals on scales, near dimerite in form (p. 480). $H = 5$ $G = 4.537$. Luster vitreous to opaque. Color deep blood-red. Streak ochre yellow. Optically $n = 2.181$ $\epsilon = 2.210$. From the Harnag mine, Fagaberg, near Fensberg, Värmland, Sweden, also at Quilua, a rock called guafante, southwest of Ouro Preto, Minas Geraes, Brazil.

Geleite. Magnesian iron titanate, $Mg.FeTiO_3$. Hexagonal rhombohedral. Structurally close, similar to hematite. Usually massive, as rolled pebbles. $H = 6$ $\epsilon = 4$. Color bluish or brownish black. Optically $n = 2.31$ $\epsilon = 1.95$. From the gem gravels of the Rakwana district, Ceylon.

Bixbyite. $FeMn_2O_4$. In black geometric crystals. X-ray study shows a body-centered cubic lattice with atoms molecules to the unit cell. $H = 6.65$ $G = 6.46$. Occurs with topaz in cavities in rhyolite from Utah. Noted at Rabca, Gipona, Spain, and in Valle de las Plumas, northern Patagonia.

Högbomite. Hoegbomite. An oxide corresponding to $RO.2R_2O_3$ with $Al_2O_3.Fe_2O_3$, $Mg.Fe_2$ chiefly. Rhombohedral. $\epsilon = 1.56$. Color black. Cleavage imperfect parallel to base and rhombohedron. Fracture conchoidal. $H = 6.5$ $G = 3.81$. Optically $n = 1.553$ $\epsilon = .903$. Pleochroic. F bright yellow-brown. G dark yellow-brown. Occurs as a rock-making mineral associated with iron ores, magnetite, hematite, pleonaste, caraduate, etc. in the Hoegbomite district, Lapland. Also found in magnetite-bearing ore at Isasmeit in Soudmøre, Norway. Identified in microscopic form in a spinel mine near Whitson, Virginia.

Sitapapite. $(MnFe)_2(FeO_2)Mn_2.3CaO$. Not crystallized. Good cleavage. $H = 7$ $G = 5.0$. Color deep bronze. Streak black. Weakly magnetic. Found at Sitapur, District Allahabad, Central Provinces, India.

Yagelaphanite. $3Mn_2O_3.2Fe_2O_3$. Cleavage parallel to octahedron or tetragonal prisms. $H = 6.5$ $G = 4.8$. Color bronze to dark steel gray. Streak dark brown to strong magnetic. Completely soluble in acids. Found at Belangur, District Nagpur, Central Provinces, and at Gravuf, District Visagapatnam, Madras, India.

III. Intermediate Oxides

The species here included are retained among the oxides although chemically considered they are properly oxygen-salts, auriferates, ferrates, manganates, etc., and hence in a strict classification to be placed in section 5 of the Oxygen-salts. The one well-characterized group is the Spinel Group.

Spinel Group. $R_2R_2O_4$ or $RO.R_2O_3$. Isometric

Aluminum Spinels

Spinel

Ceylanite, pleonaste, ferro-pleonaste
Magnesiochromite, psedonite

Hercynite

Pseudite

Chromohercynite

Gahnite (Gahnite)

Dynalite, Krenittomite

Galaxite

$MgO.Al_2O_3$

$(Mg.Fe)O.(Al.Fe)_2O_3$

$Mg.FeO.(Al.Fe)_2O_3$

$FeO.Al_2O_3$

$(Fe.Mg)O.(Al.Fe)_2O_3$

$FeO.(Al.Fe)_2O_3$

$ZnO.Al_2O_3$

$(Zn.Mg.Fe.Mn)O.(Al.Fe)_2O_3$

$Mn.Fe.MgO.(Al.Fe)_2O_3$

Iron Spinels

Magnetite

$FeO.Fe_2O_3$

Magnesioferrite

$Mg.Fe_2O_3$

Franklinite

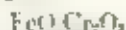
$(Fe.Zn.Mn)O.(Fe.Mn)_2O_3$

Jacobinite

$(Mn.Mg)O.(Fe.Mn)_2O_3$

Chromium Spinel

Chromite

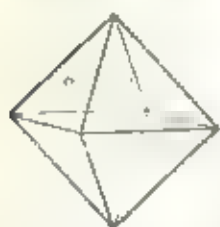


The species of the Spinel Group are characterized by isometric crystallization, and, further, the octahedron is throughout the common form. X-ray studies show that the members of the spinel Group have the same isometric atomic structure. This same structure is shown by a number of artificial compounds having the same type of chemical molecule as well as by the mineral hastite (cf. p. 440). For spinel the structure may be described as having the O atoms arranged on a face-centered cubic lattice, with the Mg atoms lying in the center of tetrahedral groups of four O atoms while the Al atoms are each surrounded by a group of six O atoms. All of the species are hard, those with nonmetallic luster up to 7.5-8, the others from 5.5-6.5.

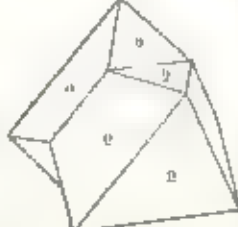
SPINEL.

Isometric. Usually in octahedrons, sometimes with dodecahedral truncations, rarely cubic. Twins, tw. pl and comp. face $\{111\}$, common (fig.

741



742



742), hence often called *spinel-twins*, also repeated and polysynthetic, producing tw. lamellae.

Cleavage: $\{111\}$ imperfect. **Fracture** conchoidal. **Brittle.** **H.** = 8. **G.** = 3.5-4.1. **Luster** vitreous, splendent to nearly dull. **Color** red of various shades, passing into blue, green, yellow, brown and black; occasionally almost white. **Streak** white. **Transparent**

ent to nearly opaque. **Refractive index:** n variable with composition, 1.7155-2.00.

Comp. Magnesium aluminates, $\text{MgAl}_2(\text{O})_4$, or $\text{Mg}(\text{O}) \cdot \text{Al}_2(\text{O})_3$ = Alumina 71.8, magnesia 28.2 = 100. The magnesian may be in part replaced by ferrous iron or manganese, and the aluminous by ferric iron and chromium.

Var. **Red Spinel**, or **Magnesian Spinel.** Clear red or reddish transparent to translucent sometimes nontransparent. $G_s = 3.63$. Common on a small scale, some of the fine specimens are worthy of study to which the red color has been ascribed. The color may vary: a) *Spinel Ruby*, deep red; b) *Bohai-Ruby*, rose-red; c) *Kulnells*, yellow or orange-red; d) *Alumina*, colorless.

Chromite, or **Plumose Iron-Magnesian Spinel.** Color dark green, brown to black, mostly opaque or nontransparent. $G_s = 3.5-3.6$. Contains iron, replacing the magnesian and perhaps also the aluminous, hence the term is $\text{Mg}(\text{Fe} \cdot \text{O}) \cdot \text{Al}(\text{Fe} \cdot \text{O})_2$ or $\text{Mg}(\text{Fe} \cdot \text{O}) \cdot \text{Al}(\text{Fe} \cdot \text{O})_2$. That it has been called *chromite* is a mistake.

Magnesian Chromite, **Iron-chrome Spinel.** Contains chromium and also has the magnesian largely replaced by iron. $\text{Mg}(\text{Fe} \cdot \text{O}) \cdot \text{Al}(\text{Cr} \cdot \text{O})_2$, hence lying between spinel proper and chromite. $G_s = 4.28$. Color dark yellowish-brown or greenish-brown. Transparent to nearly opaque.

Pyrrhotite, etc. B.B. alone indistinct. Slowly soluble in tartar, more readily in salt of phosphorus, with which it gives a reddish bead while hot, becoming faint chrome-green on cooling. Black structure gave reason for iron with the fluxes. Soluble with difficulty in concentrated sulfuric acid. Dissolved by fusion with potassium persulfate.

Diff. Distinguished by its octahedral form, its hardness and cleavage, zircon has a higher specific gravity, the true ruby (p. 486) is harder and is distinguished optically, garnet is colorless and smaller.

Micro. In thin section shows light color and high relief. Isotropic.

origin; it occurs commonly in veins associated with acid igneous rocks. Found at Itzehou and near by at Orenburg in the Ural mts. in the Harz Mts. in Germany, Sweden, at Långban in the north of Sweden, from near Ouro Preto, Minas Geraes, Brazil. Occurs intimately mixed with calcite in the waterfalls district, Arkansas.

Enterobite. Zinc-haumanite. $\text{ZnO} \cdot \text{MnO}_2$. Tetragonal. Octahedral habit. Perfect basal cleavage. Black. Brown-black streak. $d_{100} = 1.54$. $d_{010} = 2.0$. $d_{001} = 6.0$. $d_{111} = 1.58$. R. H. index = 1.54. Occurs at Franklin, New Jersey, and at the Wolf-ton mine, Jefferson Co., near Leadville, Colorado.

Hollandite. A manganese of manganese barium and ferric iron. Tetragonal. Prismatic habit. Crystals up to 2 inches in length. Fine faces very striated. Perforated with low pyramidal faces having 4 faces. Has sharp edges. The crystals consist of polymorphous and suggest a scale of a few degrees in the structure group. $d_{100} = 4.6$. $d_{010} = 1.54$. $d_{001} = 1.54$. Color silvery-gray. Occurs in the waterfalls district of the Central Province of India, a Kyanite from the same district, also at Saugor in India, where in the black wash district near the Nagpur and Balaghat districts, Germany, described as a manganese-lead manganese from the waterfalls district of the Harz Mts. in Germany. Arizona has been shown to be a part of the waterfalls district and some of the mineral. Romanzofite from Romanzof Island, Alaska, has been described as a mineral. The mineral has been shown to be a mixture of manganese and iron, and is a mineral.

Cedraite. $\text{Hf} \cdot \text{MnO}_2$. In coarse masses. Color steel-gray. $d_{100} = 4.6$. $d_{010} = 1.54$. $d_{001} = 1.54$. Occurs in the waterfalls district of the Harz Mts. in Germany.

Manganite. $\text{Pb} \cdot \text{MnO}_2$. In coarse masses. Color steel-gray. $d_{100} = 4.6$. $d_{010} = 1.54$. $d_{001} = 1.54$. Color steel-gray. Occurs in the waterfalls district of the Harz Mts. in Germany. In the Harz Mts. in Germany, described as a manganese-lead manganese from the waterfalls district of the Harz Mts. in Germany. Arizona has been shown to be a part of the waterfalls district and some of the mineral. Romanzofite from Romanzof Island, Alaska, has been described as a mineral. The mineral has been shown to be a mixture of manganese and iron, and is a mineral.

Crednerite. $\text{ZnO} \cdot \text{MnO}_2$. In coarse masses. Color steel-gray. $d_{100} = 4.6$. $d_{010} = 1.54$. $d_{001} = 1.54$. Occurs in the waterfalls district of the Harz Mts. in Germany. In the Harz Mts. in Germany, described as a manganese-lead manganese from the waterfalls district of the Harz Mts. in Germany. Arizona has been shown to be a part of the waterfalls district and some of the mineral. Romanzofite from Romanzof Island, Alaska, has been described as a mineral. The mineral has been shown to be a mixture of manganese and iron, and is a mineral.

Diopside. $\text{CaO} \cdot \text{FeO}$. Rhombohedral. Crystals tabular parallel to base to be and the base is black. Occurs near Leadville, Colorado. In the Harz Mts. in Germany, described as a manganese-lead manganese from the waterfalls district of the Harz Mts. in Germany. Arizona has been shown to be a part of the waterfalls district and some of the mineral. Romanzofite from Romanzof Island, Alaska, has been described as a mineral. The mineral has been shown to be a mixture of manganese and iron, and is a mineral.

Magnetoplumbite. An oxide of iron, manganese and lead. $2\text{FeO} \cdot \text{MnO}_2$. Hexagonal. Crystals black. Occurs near Leadville, Colorado. In the Harz Mts. in Germany, described as a manganese-lead manganese from the waterfalls district of the Harz Mts. in Germany. Arizona has been shown to be a part of the waterfalls district and some of the mineral. Romanzofite from Romanzof Island, Alaska, has been described as a mineral. The mineral has been shown to be a mixture of manganese and iron, and is a mineral.

Plumbotellurite. $\text{PbO} \cdot 2\text{TeO}_2$. Rhombohedral. Crystals black. Occurs near Leadville, Colorado. In the Harz Mts. in Germany, described as a manganese-lead manganese from the waterfalls district of the Harz Mts. in Germany. Arizona has been shown to be a part of the waterfalls district and some of the mineral. Romanzofite from Romanzof Island, Alaska, has been described as a mineral. The mineral has been shown to be a mixture of manganese and iron, and is a mineral.

Zincite. ZnO . In coarse masses. Color steel-gray. $d_{100} = 4.6$. $d_{010} = 1.54$. $d_{001} = 1.54$. Occurs in the waterfalls district of the Harz Mts. in Germany. In the Harz Mts. in Germany, described as a manganese-lead manganese from the waterfalls district of the Harz Mts. in Germany. Arizona has been shown to be a part of the waterfalls district and some of the mineral. Romanzofite from Romanzof Island, Alaska, has been described as a mineral. The mineral has been shown to be a mixture of manganese and iron, and is a mineral.

BRAUNITE.

Tetragonal. Axis $c = 0.9922$. Commonly in octahedrons nearly symmetrical in angle (pp') $\angle \text{III} \cdot \text{A} \cdot \text{III} = 70^\circ$. Also massive. X-ray study shows eight molecules to the unit cell.

Cleavage pp' (111) perfect. Fracture uneven to subconchoidal. Brittle. $H = 6.65$. $G = 4.75-4.82$. Luster submetallic. Color and streak, dark brownish black to steel-gray.

Comp. $3\text{Mn}(\text{MnO})_2 \cdot \text{MnSiO}_3 = \text{Silica } 10.0$, manganese protoxide 11.7, manganese sesquioxide 78.3 = 100.

Although the above formula agrees closely with the analyses, probably a better way of expressing the composition is to consider it as a mixture of the isomorphous molecules $\text{Mn}(\text{MnO})_2$ and MnSiO_3 in proportions nearly 3:1.

Pyrr., etc. B.B. infusible. With borax and salt of phosphorus gives an amethystine bead in C.F., becoming colorless in R.F. With soda gives a bluish green bead. Dissolves in hydrochloric acid leaving a residue of gelatinous silica. Marcelline gelatinizes with acetic.

Obs. In company of secondary but may be of primary origin. Occurs in veins traversing porphyry at Obersiebenbrunn near Linz, Austria; Thuringia, from near Hild; Harz Mts., at St. Marcel, Piedmont. At Idaghsahtyts, and elsewhere in Sweden. It is also occasional in quantities at Kacharwak, district of Nagpur, Central Provinces. From Miguel Burrier and Otero Prieto, Minas Geraes, Brazil. *Marcelline* (heterocochite, from St. Marcel, Piedmont), is impure limonite.

IV. Dioxides, RO_2

Rutile Group. Tetragonal

Cassiterite	SnO_2	0.6723	Rutile	TiO_2	0.6442
Polarite	MnO_2	0.6647	Plattnerite	PbO_2	0.6764

The **RUTILE GROUP** includes the dioxides of the elements tin, manganese, titanium, and lead. These compounds crystallize in the tetragonal system with closely similar angles and axial ratio, furthermore in habit and method of twinning there is much similarity between the two best known species included here. Chemically these minerals are sometimes considered as salts of their respective acids, as stannic metastannate, $SnO \cdot SnO_3$, for cassiterite and titanic metatitanate, $(TiO)TiO_3$, for rutile.

X-ray study shows for cassiterite an atomic structure in which the tin atoms are arranged in a body-centered tetragonal unit cell. The oxygen atoms lie in the same horizontal planes as the tin atoms and are grouped in pairs along the vertical axis. Thus, among the pairs of oxygen atoms have the direction of one or the other of the prism diagonals and alternate in direction in each successive horizontal atomic layer. The other members of the group show closely similar structures.

With the Rutile Group is sometimes included a form $ZrO_2 \cdot 8H_2O = 0.6404$. The atomic structure is like that of the group with the zircon atoms placed at the corners of the tetragonal unit cell. The observed axial ratio of this variety is 0.6404, however, which is smaller than the theoretical value for the ideal species (theoretical $c/a = 0.642$). The phosphorus compound VPO_2 is also closely similar in crystal form and structure to this group; this seems to be true of MnO_2 and PbO_2 also (see Table VII).

It may be noted that ZrO_2 , as the species in which it crystallizes in the monoclinic system.

CASSITERITE. Tin-stone, Tin Ore.

Tetragonal. Axis $c = 0.6723$.

$\alpha\alpha'$, 101 \wedge 011 = $90^\circ 28'$	
$\alpha\alpha''$, 101 \wedge 101 = $67^\circ 40'$	
$\alpha\alpha'$, 111 \wedge 111 = $68^\circ 10'$	
$\alpha\alpha''$, 111 \wedge 111 = $87^\circ 7'$	

ma, 110 \wedge 111 = $45^\circ 27'$	
zz, 131 \wedge 23 = $20^\circ 33'$	
rrm, 321 \wedge 321 = $61^\circ 42'$	

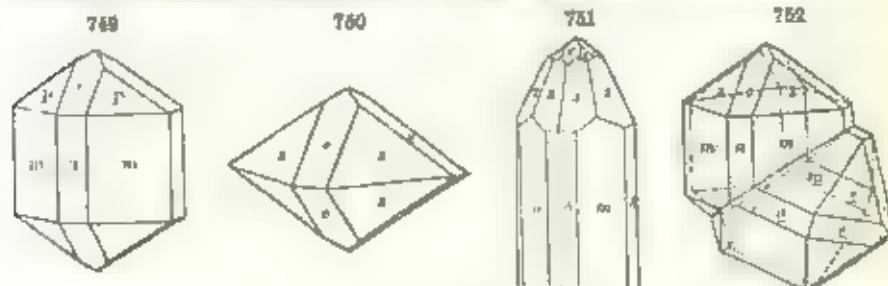
Twins common, tw pl (101), both contacts and penetration-twins (Fig. 752), often repeated. Crystals low pyramidal, also prismatic and acutely terminated. Sometimes very slender needle-like. Prism zone vertically striated. For atomic structure see above. Often in reniform shapes, structure fibrous divergent, also massive, granular or compact, in a bedded grade.

Cleavage (100) imperfect. α (111) more so. α (110) largely distinct. Fracture subconchoidal to uneven. Brittle. $H = 6-7$. $G = 0.8-7.1$. Luster a lustrous, and crystals usually splendid. Color brown or black; sometimes red, gray, white, or yellow. Streak white, grayish, brownish.

Nearly transparent to opaque. Optically + Indices $n = 1.9906$, $e = 2.0034$.

Var. *Ordinary*. Tin-oxide. In crystals and massive.

Wood-tin. In botryoidal and residual shapes. Same in structure and related to tin-stannite although very compact with a bluish brownish, of a reddish-brown, looking somewhat as dry wood in colors. Total appearance is the same as stannite. Stannite is the ore in the state of sand as it occurs along the base of a residual tin ore. Stannite was described as a silicate of tin occurring in highly siliceous masses in the tin veins of Bolivia but is probably a mixture of wood-tin and stannite.



Comp. Tin dioxide, $\text{SnO}_2 = \text{Oxygen } 21.4$, tin $78.6 = 100$. A little Th_2O_3 is sometimes present, also Fe_2O_3 .

Pyrr., etc. B.B. alone unaltered. On charcoal with soda reduced to metallic tin, and gives a white coating. With the fluxes it fuses and gives reactions of iron and manganese. On slightly heated upon by acid. When fragments of crystals are placed in acids to smelt them and together with a little metal in acid, the cassiterite becomes coated with a black gray deposit of metallic zinc which becomes bright on friction.

Diff. Distinguished by its high specific gravity, hardness, infusibility, and by its yielding metallic tin in B.B. resembles more variously of garnet, sphalerite and black tourmaline. Specific gravity 8.5 higher than that of rutile 4, wolframite is usually found.

Anal. Cassiterite has been artificially prepared by the action of aqueous upon tin tetrachloride in a heated tube and by other similar methods employing heated vapors.

Obs. - Cassiterite is the chief ore of tin and is found in many localities although the important occurrences are few and are concentrated in a few places. It has been noted as an original constituent of igneous rocks but is commonly seen in veins or strings of quartz either young or close to granitic rocks or pegmatites. It has also been observed in quartz porphyry and rhyolite. It is commonly associated with minerals containing boron and fluorine which indicates a paragenetic origin. The granites are frequently altered into material known as greisen in which the tin-bearing have been altered in place and together with arsenic, antimony, etc. The commonly associated minerals are quartz, wolframite, scheelite, also mica which is often a white, or bluish, mica, tourmaline, arsenic, apatite, fluorite, further perite, arsenopyrite, sphalerite, molybdenite, native bismuth, etc. frequently occurs in veins and greisen.

Large deposits of residual tin ores occur in Cornwall. These were formerly very important but have been largely exhausted. The Dolomieu mine near Redoubt is more than 3 miles long and has been worked for more than 300 years. The cassiterite occurs often in fine crystals and is also as wood-tin and stannite. The more famous specimens of apatite are St. Agnes, California, California, St. Just, St. Just, Pachuca. Pseudomorphs after feldspar are found at W. and Coates near St. Agnes. On the continent of Europe unusual specimens are found at Schlegel and Schlegel, Germany, Krupka and Zinnwald (Czech), in northwest Bohemia. Greenish crystals in the neighboring district of Saxony at Altenberg and Ehrenfriedersdorf. Fine crystals after wolframite are found at Villeder, Moravia, France. Near Pukara on Lake Luga, Finland.

Important deposits of small plants, occur on the Malay Peninsula and the neighboring islands Borneo and Borneo off the coast of Sumatra. Cassiterite is abundant in New South Wales over an area of 8500 square miles, fine crystals coming from E. and W. of the town of Glen Eden and Elmore, and in the New England Range. It also occurs in Victoria,

in Queensland and at Mt. Bischoff Tasmania. From South West Africa. Important deposits occur in Bolivia near La Paz, Oruro, and Potosi with associated in veins of lead, silver, and bismuth. In Mexico from the states of Durango, Coahuila, Jalisco, etc.

Caeserite does not occur in quantity in the United States. It is most commonly found in sandstone in the pegmatite veins. Other occurrences are found in New England as at Norway, Hallowell, and elsewhere in Oxford Co., Maine, from New Hampshire, Massachusetts, and Connecticut. In Virginia, in Irish Creek, Rockbridge Co., with wolframite. In North and South Carolina and Alabama. In South Dakota near Huron Peak and near Custer City in the Black Hills, where it has been mined. Low-grade deposits occur at Tenebril in the Santa Ana Mountains, Riverside Co., California. Has also been mined in the York district, Seward Peninsula, Alaska.

Use. The most important one of the

Pyrochlore *Manganese* *Pyrochlore*. *Pyrochlore*. Tetragonal. Atomic structure similar to that of zirconite, see p. 196. In composite parallel groupings of minute crystals, also forming the outer shell of crystals having the form of manganese. $H = 6-6.5$, $G = 4.9-5.2$. Luster vitreous. Color light steel-gray or iron-gray. Streak black. Definite and well-crystallized pyrochlore is found only at Tenebril in Bolivia, Czechoslovakia, having been derived by the action of contact. It is distinguished from pyrochlore by its hardness and its anhydrous character. Like pyrochlore it is often a pseudomorph after zirconite.

RUTILE

Tetragonal. Axis $c = 0.64415$.

$$R\infty \ 310 \wedge \bar{3}10 = 36^\circ 54'$$

$$\infty \ 10 \wedge 011 = 45^\circ 2'$$

$$\infty \ 10 \wedge \bar{1}01 = 65^\circ 34'$$

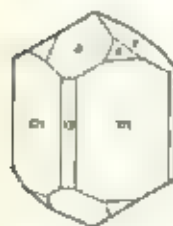
$$\infty \ 111 \wedge \bar{1}11 = 75^\circ 25'$$

$$\infty \ 111 \wedge \bar{1}11 = 84^\circ 46'$$

$$\infty \ 311 \wedge \bar{3}11 = 29^\circ 6'$$

Twins (1) by (1) c (101) of ungeminated (Figs 755, 756), also contact-twins of very varied habit as sometimes sixlings and eightlings (Fig. 42a, p. 185, Fig. 439, p. 188). (2) by (301), rare contact-twins (Fig. 441, p. 188). Crystals

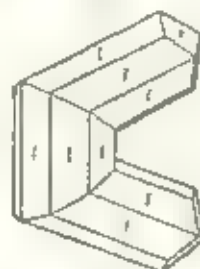
753



754



755



are commonly prismatic, vertically striated or furrowed, often slender acicular. Occur only in compact masses. For atomic structure, see p. 476.

756



(See page 100) and (101) (111) (111) in traces. Fracture schistose to uneven. Brittle. $H = 6-6.5$, $G = 4-4.5$ (2) also to 5.2. Luster metallic-adamantine. Color reddish brown passing into red, sometimes yellowish bluish, white, black, rarely grass-green. Transmitted light deep red. Streak pale brown. Transparent to opaque. Optically +. Refractive indices high: $\omega = 2.618$, $\epsilon = 2.0020$. Birefringence very high. Some times also strongly black.

Comp. Titanium dioxide. $TiO_2 =$ (oxygen 40.0, titanium 60.0) = 100. A little iron is usually present, sometimes up to 10 per cent. While the iron

present is often reported as ferric the probability is that in the unaltered mineral it existed in the ferrous state.

The formula for the material may, as yet, not be a definite titanate ($\text{TiO}_2 \cdot \text{TiO}$). With this the extra titanium oxide may be considered as a solid solution and so account for the composition present. It has been suggested that the typical molecule FeTiO_3 is also a complex ion and that the Fe^{2+} belongs to the same group as Ni^{2+} and Mn^{2+} (see *Table I* below). It has been noted that the Fe^{2+} is a strong oxidizing agent in the presence of the Fe^{3+} and the presence of the latter in this way could account for the composition shown by many of the samples.

Var. *crystallina*. Brownish red and other shades, not black. $G = 4.14-4.25$. Transparent quartz is sometimes penetrated by silty with needles or capillary crystals. Dark smoky quartz penetrated with the same or value or reddish quartz. In the *fluorescence* of the Var. *crystallina* from a number of parallel positions on table or crystals of the same size somewhat irregular in shape. Red, rotated twin crystals of slender crystals are frequent in aggregate. Also.

[illegible][illegible]

Diff. characterized by: 1) good or no demarcation; 2) lighter not two-shaded red color
differs from *luteus* in: 1) variability, 2) color being relatively unaltered when heated since
it is. Some specimens of *luteus* are characterized by:

Micro In thin sections shows red-brown to yellow color, very high relief and high order of interference color.

Artal. It is also seen formed artificially by heating thorium oxide with boric oxide with sodium hydroxide and the orthochloride and monochloride have all been found by bromine, whereas it is thought that the monochloride is formed from monochloride and gasolene. It is also formed at the highest temperatures, bromine at lower temperatures, and orthochloride at the lowest of all. It is apparently the most stable form of Th₂ and is considered to be the most common monochloride have been found that have a very low boiling point.

[illegible]

It is widespread in small amounts, often in microscopic crystals. It is most probably identical with the heavy yellow barite. A specimen of *Alveolaria* composed of this mineral is known from the coast of Rangoon in the Bay of Bengal, and from a locality in the Himalayas. It is also found in the French Alps, in the mountains of the Jura in Switzerland, in the Val Tignes, in the French Alps, at St. Moritz, in the Italian Alps, and elsewhere. In France, at Saint Yrieix, with *Lophoceros*, *Holostichia*, in Norway at Sævi, Kragerø, Hæser etc. From Blankenberg, Svalbard to South Australia. From Mount Garma, Borneo.

[illegible]

For specimens of this rare apple come from Val Lamoignon, Canada and elsewhere in Quebec and, from Massachusetts, Minnesota, Braun, West national, Vermont, Alexander Co., North Carolina.

Timonaxite was originally found in the Uken Mts. Russia, also noted from Ampangale near Man-irany, Madagascar. *Sibirite* was originally described from Ureyevsk, Siberia. It may also occur found in Madagascar at Tongafana, south of Betafo and at F. Fina, about 100 miles to the east of Kevebe, Pennangton Co., South Dakota.

Use. — A source of titanium.

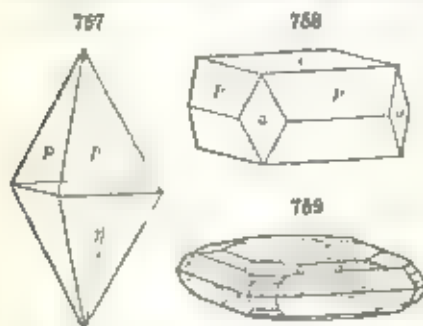
Platinite. *Leucophaea* PbO_2 . Tetragonal. Structure that of the Rutile Group, see p. 496. Rarely in prismatic crystals, usually massive. $H = 5-5.5$. $G = 8.5$. Luster submetallic. Color iron-black. Streak chestnut-brown. From Scotland at Leadhite Lough, north of Warrickhead, Dumfries. Also in Idaho at M. Blau, Coeur d'Alene district, and elsewhere in Idaho, and in the Colorado district, Lead Co.

Baddeleyite. Zirconium dioxide, ZrO_2 . Contains small amount of hafnium oxide. In tabular monoclinic crystals. Average, 700. $H = 6.5$. $G = 5.5-6.0$. Colorless to yellow-brown and black. Optically $\alpha = 2.13$, $\beta = 2.19$, $\gamma = 2.20$. $2V = 39^\circ$. At $\mu = 0.10$. $\chi = 1.1$. Dispersion, strong, $\mu > \nu$. From Ceylon from Brach near Galle. Minor sources and Jacuparanga, São Paulo, Brazil. From near Amdo, Vostok, Siberia, Sweden. Noted in Mts. Sennar, New York. Also near Bowman, Montana. Various minerals occurring as baddeleyite in the diamond sands of Brazil are known as *para-baddeleyite*. Some of them consist of nearly pure TiO_2 , others of nearly pure ZrO_2 , while others are various phosphates.

OCTAHEDRITE, Anatase.

Tetragonal. Axis $c = 1.7771$.

Commonly octahedral in habit, either acute (p , 111), or obtuse (o , 117); also tetragonal, c 001 predominant, rarely prismatic crystals frequently highly modified. X-ray analysis shows that the Ti atoms lie on a slightly deformed diamond lattice (see p. 49) with the O atoms arranged in pairs on either side of the Ti atoms in vertical lines.



pp	$01 \wedge 011 = 76^\circ 5'$
oo	$01 \wedge 01 = 121^\circ 16'$
po	$11 \wedge 111 = 82^\circ 9'$
pp	$111 \wedge 111 = 130^\circ 70'$
oo	$113 \wedge 113 = 54^\circ 1'$
po	$117 \wedge 117 = 27^\circ 30'$

Cleavage c (001) and p (111) perfect. Fracture subconchoidal. Brittle. $H = 5.5-6$. $G = 3.82-3.95$, sometimes 4.11-4.16 after heating.

Luster adamantine or metallic-adamantine. Color various shades of brown, passing into indigo-blue, and black, greenish yellow by transmitted light. Streak uncolored. Transparent to nearly opaque. Optically — Birefringence rather high. Indices $\omega = 2.534-2.564$, $\epsilon = 2.488-2.497$, varying probably with iron content. Sometimes abnormally biaxial.

Comp. Titanium dioxide $TiO_2 =$ Oxygen 40.0, titanium 60.0 = 100. Commonly contains small amounts of iron oxide.

Pyrr., etc. — Same as for rutile.

Artf. — See under rutile.

Obs. Variety of secondary origin, derived from the alteration of other titanium-bearing minerals. Occurs in granite, quartz, nepheline, gneiss, chlorite and mica schists associated with quartz and/or titanite, ilmenite, and/or rutile and brookite. Iron is associated in the ilmenite. Also, the variety sometimes long supposed to be xenotime at Auroville, Val Tignes, France. Also found in fine crystals in the matrix of fluorite d'Audoubert, France, associated with feldspar, anorthite, and zirconite. In chlorite near

Variscite. Devonshire. In Mass. *Variscite*, Brazil, a splendent crystals in quartz. In the United States variscite has been found in Mason's quarry at Warren, N. H. From Magnet Cove, near Hot Springs, Arkansas. The crystals which are larger than most of plagioclase and reaching a centimeter in diameter have been found on Weaver's rock, Graham Co., Colorado.

BROOKITE

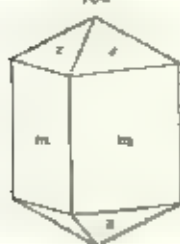
Orthorhombic. Axes $a : b : c = 0.8416 : 1 : 0.9444$

μ_{100}	$110 \wedge \bar{1}10 = 60^\circ 10'$	μ_{111}	$112 \wedge \bar{1}12 = 44^\circ 23'$
μ_{110}	$112 \wedge \bar{1}12 = 13^\circ 46'$	μ_{111}	$122 \wedge \bar{1}22 = 78^\circ 7'$
μ_{111}	$112 \wedge \bar{1}12 = 44^\circ 40'$	μ_{111}	$110 \wedge \bar{1}10 = 46^\circ 42'$

(Only in crystals of varied habit. Atomic structure is similar to that of columbite, see p. 495.)

(Cleavage on (110) indistinct, $c(001)$ striations so. Fracture subconchoidal to uneven. Brittle. $H = 5.5-6$. $G = 5.67-6.05$. Luster metallic.

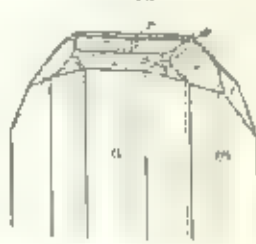
780



761



762



Isomorphous to submetallic. Color light-brown, yellowish, reddish, brown, and transparent, also brown to iron-black, opaque. Streak uncolored to grayish or yellowish. $\alpha = 2.583-2.584$, $\beta = 2.585-2.586$, $\gamma = 2.705-2.74$, optically +. Bx always \pm (100). Ax pl. || $c(001)$ for bl. & red green light. $c(001)$ for red and yellow light. $c(110)$ for a yellowish green color. Strong dispersion. Atypical interference figure (see p. 326).

Comp. = Titanate of iron, Fe₂O₃ = oxygen 40.0, titanium, 60.0 = 100.

Prt. = Same as for rutile.

Anal. See under rutile.

Obs. In some of origin and associations brookite is similar to rutile. Found in the same places as the rutile. In the United States near Mason's quarry near Warren, N. H. In the United States near Magnet Cove, near Hot Springs, Arkansas. In the United States near Hot Springs, Arkansas. In the United States near Hot Springs, Arkansas. In the United States near Hot Springs, Arkansas.

In the United States near Hot Springs, Arkansas. In the United States near Hot Springs, Arkansas. In the United States near Hot Springs, Arkansas. In the United States near Hot Springs, Arkansas.

Named after the English mineralogist, A. J. Brooke, 1771-1877.

PYROLUSITE

Orthorhombic, but pseudorhombic, commonly after manganite. X-ray study shows that pyrolusite has the same atomic structure as perovskite, which is apparently the only crystalline form of MnO₂. Laminar columnar often divergent, also granular massive and frequently in reniform crusts.

Not often showing cleavage. $H = 2-2.5$. $G = 4.7-4.86$. Luster metallic. Color iron-black, dark steel-gray, sometimes bluish. Streak black or bluish black, sometimes submetallic. Opaque.

Comp. - Manganese dioxide, MnO_2 , like psilomelane (p. 498). Commonly contains a little water, 2 per cent.

Fr., etc. Like psilomelane but most varieties yield some water in the closed tube.

Dif. Manganese dioxide has been shown to form iron pyrites in a reaction of iron ore with H_2 . It is also a common peroxide of iron in pyrites and also in some other minerals.

Obs. Manganese dioxide occurs in many forms, but the most characteristic is as a black, earthy, or fibrous mineral. It is often found in the form of small, black, earthy nodules, or as a black, fibrous mineral. It is also found in the form of small, black, earthy nodules, or as a black, fibrous mineral. It is also found in the form of small, black, earthy nodules, or as a black, fibrous mineral.

Manganese dioxide is a common mineral in many rocks, especially in igneous rocks. It is often found in the form of small, black, earthy nodules, or as a black, fibrous mineral. It is also found in the form of small, black, earthy nodules, or as a black, fibrous mineral. It is also found in the form of small, black, earthy nodules, or as a black, fibrous mineral.

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B. HYDROXIDES

Among the hydroxides the **Hydroxide Group** is well characterized. Here belong the hydroxides of aluminum, iron and manganese. The general formula is properly written $RO(OH)$. The three species here included are characterized in crystallization with related angles in axial ratios. This relationship is detected from the magnification of the prismatic zone.

Another less prominent group is the **Hydroxide Group** including the rhombohedral species $Al(OH)_3$, $Mg(OH)_2$, and $Pyrochroite$, $Mn(OH)_2$.

Hydroxide, $Al(OH)_3$, and **Pyrochroite**, $Mn(OH)_2$, are also treated, and further **Hydroxide** and **Pyrochroite**.

Diaspore Group. $RO(OH)$, or $R_2(O)_2H_2O$ orthorhombic

		a	b	c	$\frac{c}{a}$
Diaspore	$Al(OH)_3$	0.9372	1	0.6010 or 0.6443	
Goethite	$Fe(OH)_3$	0.935	1	0.6068 or 0.6406	
Manganite	$Mn_2O_3H_2O$	0.8441	1	0.5348 or 0.6163	

DIASPORE.

Orthorhombic. Axes a b c = 0.9372 1 0.6010. Crystals prismatic, mm " 110 \times 115, = 88° 17' usually thin, flattened. b 0.10 sometimes acicular. Also foliated massive and in thin scales sometimes tabular.

Cleavage $b \ 010$ eminent, $a \ 210$ less perfect. Fracture conchoidal, very brittle. $H = 5.5-7$ $G = 3.3-4.5$ Luster (mainly), pearly on cleavage-surface, elsewhere vitreous. Color whitish, grayish white, greenish gray, or brown, very rich, to coppery. At times pleochroic. $X =$ dark violet or reddish brown, $Z =$ faint yellow. Transparent to subtranslucent. Optically - Birefringence high. $\Delta x \text{ pl. } b \ 010$ $\Delta x \text{ a } 100$ Dispersion $p < \text{red} < 2V = 84^\circ$ $\epsilon = 1.702$ $\mu = 1.722$ $\gamma = 1.750$
 Comp. $Al_2O_3 \cdot H_2O$ or $Al_2(OH)_2 \cdot H_2O =$ Alumina 80.0, water 15.1 = 100

Per., etc. In the closed form usually perceptibly strong, penetrating into water, and at a high temperature, it is attacked by acids, but after exposure to air it gives a deep blue color. Not attacked by acids, but after exposure to air it gives a deep blue color.

Diff. The gemstone is a hard, white and pearly, and the blue is a deep, rich blue, and the color is due to the presence of iron in the crystal. It is a very hard stone, and the color is due to the presence of iron in the crystal.

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Loc. The gemstone is a hard, white and pearly, and the blue is a deep, rich blue, and the color is due to the presence of iron in the crystal. It is a very hard stone, and the color is due to the presence of iron in the crystal.

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GOETHITE.

783

Orthorhombic. Axes $a \ b \ c = 0.9185 \ 1 \ 0.6008$

$\epsilon_{100} = 1.0$ $\epsilon_{111} = 1.11 = 88.5^\circ$
 $\epsilon_{011} = 0.61 = 62.50^\circ$ $\epsilon_{110} = 1.11 = 88.5^\circ$

In prisms vertically striated and often flattened into scales or tables. $b \ 010$. Also in rods, foliated or in scales, massive, reniform and stalactitic with concentric and radiated structure.

Cleavage $b \ 010$ very perfect. Fracture uneven. Brittle. $H = 5.5-5$ $G = 4.28$ Luster imperfect adamantine. Color yellowish, reddish, and blackish brown. Often blood-red by transmitted light. Streak brownish yellow to ochre-yellow. Optically - (Optical axes strongly dispersed. $\Delta x_{100} = \{010\}$ for all colors. $\Delta x \text{ pl. for red} = \{100\}$,



for yellow = (001) $a = 2.26$ $b = 2.39$ $\gamma = 2.4$ Only weakly piezochroic.

Var. In some cases it is almost completely colorless, often from one edge. A small amount of yellow may be seen in the center of the crystal. The color is due to the presence of iron. It is usually found in thin plates. The color is due to the presence of iron. It is usually found in thin plates.

Comp. FeS. H. 2.5. Fract. H. 2.5. Cleavage 27.0. Mohs 6.2. Water 10.1. $n_D = 1.00$ or less. $n_{\text{max}} = 1.00$ water 10.1. $n_{\text{min}} = 1.00$

Pyrite is the most common mineral in the earth's crust. It is a common ore of iron. It is a common mineral in the earth's crust. It is a common ore of iron. It is a common mineral in the earth's crust. It is a common ore of iron.

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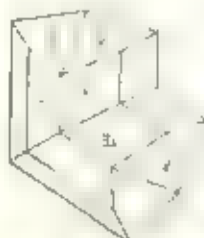
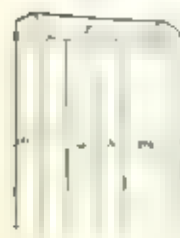
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MANGANITE

764

765



Orthorhombic. Axes $a : b : c = 0.8441 : 1 : 0.8448$

$100 \wedge 010 = 90^\circ$	$010 \wedge 011 = 37^\circ 10'$
$100 \wedge 011 = 52^\circ 50'$	$010 \wedge 011 = 52^\circ 50'$

Pyrite is the most common mineral in the earth's crust. It is a common ore of iron. It is a common mineral in the earth's crust. It is a common ore of iron. It is a common mineral in the earth's crust. It is a common ore of iron.

Pyrite is the most common mineral in the earth's crust. It is a common ore of iron. It is a common mineral in the earth's crust. It is a common ore of iron. It is a common mineral in the earth's crust. It is a common ore of iron.

protuberant, with $G = 2.44$. *Manganohydroxide* contains manganese: occurs granular; color honey yellow to brownish red. From the same source.

Pyr., etc. In the mass, a grayish white, extending opaque and friable, sometimes turning gray to brown. The mineral is very brittle, and the color is very light. It is found in small, angular, light-colored fragments, which are very light. The color is very light. The color is very light. The color is very light.

Fract. Fracture is conchoidal. The cleavage is perfect, and the structure is granular. It is harder than calc. It is softer than calc. It is softer than calc. It is softer than calc.

Obs. Occurs in the same place as the other minerals. It is found in the same place as the other minerals. It is found in the same place as the other minerals. It is found in the same place as the other minerals.

In the same place as the other minerals. It is found in the same place as the other minerals. It is found in the same place as the other minerals. It is found in the same place as the other minerals.

Pyrochroite. Manganese hydroxide. It is found in the same place as the other minerals. It is found in the same place as the other minerals. It is found in the same place as the other minerals.

Backströmite. Pyrochroite. Manganese hydroxide. It is found in the same place as the other minerals. It is found in the same place as the other minerals. It is found in the same place as the other minerals.

GIBBSITE. Hydrate of aluminum hydroxide. It is found in the same place as the other minerals. It is found in the same place as the other minerals. It is found in the same place as the other minerals.

Monoclinic. Axes $a = 6.1$, $b = 1.7089$, $c = 1.9184$. $\beta = 85^\circ 29'$. Crystals tabular, often hexagonal in aspect. Occasionally is spherical, concentric. Also in the form of small masses, irregular, with smooth surface, and often a faint fibrous structure within.

Cleavage. (001) prominent. Tough. $H = 2.5-3.5$. $G = 2.4-2.4$. Color white, grayish green or reddish white. Luster of (001) pearly, of other faces vitreous. It is very soft and brittle. It is very soft and brittle. It is very soft and brittle. It is very soft and brittle.

Comp. Aluminum hydroxide, $Al_2(OH)_6$ or $Al_2O_3 \cdot 3H_2O$. Alumina 85.4, water 14.6 = 100.

Pyr., etc. In the mass, white and opaque, and melts with water. It is found in the same place as the other minerals. It is found in the same place as the other minerals. It is found in the same place as the other minerals.

Artif. When a solution of aluminum sulfate is mixed with a solution of sodium carbonate, a white precipitate is formed. It is found in the same place as the other minerals. It is found in the same place as the other minerals. It is found in the same place as the other minerals.

Obs. Occurs in the same place as the other minerals. It is found in the same place as the other minerals. It is found in the same place as the other minerals. It is found in the same place as the other minerals.

Nitrates 5. Borates and Uranates, 6. Sulphates, Chromates and Tellurates, 7. Tungstates and Molybdates.

1. CARBONATES

A. Anhydrous Carbonates

The Anhydrous Carbonates include two distinct isomorphous groups, the **CALCITE GROUP** and the **ARAGONITE GROUP**. The metallic elements present in the former are calcium, magnesium, iron, manganese, zinc, and cobalt, in the latter, they are calcium, barium, strontium, and lead.

The species included are as follows:

1. Calcite Group. RCO_3 . Rhombohedral

		mm'	d
Calcite	CaCO_3	74° 55'	0.8543
Dolomite	$\text{CaCO}_3, \text{MgCO}_3$ Tri-rhombohedral	73° 45'	0.8322
Ankerite	$\text{CaCO}_3, \text{Mg}, \text{FeCO}_3$	73° 48'	0.8332
Magnesite	MgCO_3	72° 36'	0.8112
Siderite	FeCO_3	73° 0'	0.8184
Rhodochrosite	MnCO_3	73° 0'	0.8184
Smithsonite	ZnCO_3	72° 20'	0.8063
Sphaerocobaltite	CoCO_3		

This list gives only the prominent species of this group; the names, etc. of the isomorphous subcarbonate compounds will be found under the description of the different members.

The **CALCITE GROUP** is characterized by rhombohedral crystallization. All the species show, when distinctly crystallized, perfect rhombohedral cleavage, the angle varying from 75° (and 105°, in calcite) to 73° and 107°, in siderite. This is exhibited in the table above. For the atomic structure of calcite as shown by X-ray study see p. 41. Similar studies for the other members of the group show the same type of structure for them all. Siderite and rhodochrosite have almost identical structures thus explaining the complete miscibility of these two molecules, while in the case of calcite and magnesite the dimensions of the unit cell differ enough to explain their very limited miscibility.

2. Aragonite Group. RCO_3 . Orthorhombic

		mm'''	a : b : c
Aragonite	CaCO_3	63° 48'	0.6224 : 1 : 0.7206
Bromite	$(\text{Ca}, \text{Ba})\text{CO}_3$		
Witherite	BaCO_3	62° 12'	0.6032 : 1 : 0.7302
Strontianite	SrCO_3	62° 41'	0.6090 : 1 : 0.7239
Cerussite	PbCO_3	62° 46'	0.6100 : 1 : 0.7230

The species of the **ARAGONITE GROUP** crystallize in the orthorhombic system, but the relation to those of the Calcite Group is made more close by the fact that the prismatic angle varies only a few degrees from 60° (and 120°) and the twinned forms with the fundamental prism as twinning-plane are pseudo-hexagonal in character. X-ray study shows a complex structure which is orthorhombic but nearly hexagonal in character. The different molecules of the group replace each other to a certain degree but to a much less extent than in the Calcite Group.

Habit of crystals very varied, as shown in the figures, from oblique to acute rhombohedral, from thin tabular to long prismatic, and some combination of many types, often highly modified. Crystalline crystals exhibit a great variety of forms and habits than any other mineral.

Twins (see Figs 445-452 p. 189), (1) Tw pl (1001), common, the crystals having the same vertical axis. (2) Tw pl (0112), very common, the vertical axes inclined $27^{\circ} 30'$ and $52^{\circ} 30'$, often producing twinning lamellae as in Iceland spar, which are in many cases of secondary origin as in granular limestone (Fig. 785). (3) Tw pl (0101), but common, the vertical axes inclined $90^{\circ} 46'$ and $89^{\circ} 14'$. (4) Tw pl (1021), rare, the axes intersect at angles of $54^{\circ} 46'$ and $126^{\circ} 14'$.

Also fibrous with coarse and fine, sometimes lamellar, often granular, from coarse to impalpable and compact to earthy. Also stalactitic, tubercle, nodular and other imitative forms.

Cleavage (1011) highly perfect. Parting (0112) due to twinning. Fragments conchoidal, obtained with difficulty. $H = 3$, but varying with the direction of the cleavage face, earthy kinds softer. $G = 2.710$, in pure crystals, but varying somewhat widely in impure forms, as those containing iron, manganese, etc. Luster vitreous to subvitreous (earthy) color white or colorless, also various pale shades of gray, red, green, blue, violet, yellow, also brown and black when impure. Streak white or grayish. Translucent to opaque. Certain varieties show phosphorescence upon heating and others luminescence upon being exposed to sunlight or radiations emanating from the sun.

Optically. Birefringence very high. Refractive indices for the D line $\alpha = 1.4849$, $\epsilon = 1.4862$. Sometimes also uniaxial with $2V$ varying up to 90° . Probably due to a molecular strain. The effect has been produced artificially.

Comp. Calcium carbonate CaCO_3 (Carbon 4.4% and 56.0 = 100). Small quantities of magnesium, iron, manganese, zinc, and lead may be present replacing the calcium.

Calcareous in the stable form. Insoluble in water at ordinary pressure and over a large temperature range. The decomposition of calcareous compounds is due to the action of the acids. Also soluble in water containing carbon dioxide. Very soluble in dilute hydrochloric acid. The crystals change color slightly upon exposure to air, but the color change is extremely slight. The color change is due to the action of the acids.

Var. The variation of the mineral is due to the action of the acids. The mineral is uniaxial with $2V$ varying up to 90° . The color change is due to the action of the acids. The mineral is uniaxial with $2V$ varying up to 90° .

A. VARIETIES BASED CHIEFLY UPON CRYSTALLIZATION AND VERTICAL IMPURITIES

1. *Idiomorphic*. The crystals are small and clear, and are uniaxial with $2V$ varying up to 90° . The crystals are small and clear, and are uniaxial with $2V$ varying up to 90° . The crystals are small and clear, and are uniaxial with $2V$ varying up to 90° .

785



Section of crystalline limestone showing twinning, Fig. 785.

[illegible]

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14. The first part of the paper is devoted to the study of the properties of the function $f(x)$ defined by the equation $f(x) = \int_0^x f(t) dt$. It is shown that $f(x)$ is a constant function and that the constant is zero. The second part of the paper is devoted to the study of the properties of the function $f(x)$ defined by the equation $f(x) = \int_0^x f(t) dt$. It is shown that $f(x)$ is a constant function and that the constant is zero.

[illegible]

$\frac{1}{\sqrt{\pi}} \int_{-\infty}^{\infty} f(x) \delta(x-a) dx = f(a)$

$\frac{1}{n} \sum_{i=1}^n x_i = \bar{x}$

... ..
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... ..

1. The first part of the paper is devoted to the study of the properties of the function $f(x)$ defined by the equation

[illegible][illegible]

200 B. A. 12 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100 101 102 103 104 105 106 107 108 109 110 111 112 113 114 115 116 117 118 119 120 121 122 123 124 125 126 127 128 129 130 131 132 133 134 135 136 137 138 139 140 141 142 143 144 145 146 147 148 149 150 151 152 153 154 155 156 157 158 159 160 161 162 163 164 165 166 167 168 169 170 171 172 173 174 175 176 177 178 179 180 181 182 183 184 185 186 187 188 189 190 191 192 193 194 195 196 197 198 199 200 201 202 203 204 205 206 207 208 209 210 211 212 213 214 215 216 217 218 219 220 221 222 223 224 225 226 227 228 229 230 231 232 233 234 235 236 237 238 239 240 241 242 243 244 245 246 247 248 249 250 251 252 253 254 255 256 257 258 259 260 261 262 263 264 265 266 267 268 269 270 271 272 273 274 275 276 277 278 279 280 281 282 283 284 285 286 287 288 289 290 291 292 293 294 295 296 297 298 299 300 301 302 303 304 305 306 307 308 309 310 311 312 313 314 315 316 317 318 319 320 321 322 323 324 325 326 327 328 329 330 331 332 333 334 335 336 337 338 339 340 341 342 343 344 345 346 347 348 349 350 351 352 353 354 355 356 357 358 359 360 361 362 363 364 365 366 367 368 369 370 371 372 373 374 375 376 377 378 379 380 381 382 383 384 385 386 387 388 389 390 391 392 393 394 395 396 397 398 399 400 401 402 403 404 405 406 407 408 409 410 411 412 413 414 415 416 417 418 419 420 421 422 423 424 425 426 427 428 429 430 431 432 433 434 435 436 437 438 439 440 441 442 443 444 445 446 447 448 449 450 451 452 453 454 455 456 457 458 459 460 461 462 463 464 465 466 467 468 469 470 471 472 473 474 475 476 477 478 479 480 481 482 483 484 485 486 487 488 489 490 491 492 493 494 495 496 497 498 499 500 501 502 503 504 505 506 507 508 509 510 511 512 513 514 515 516 517 518 519 520 521 522 523 524 525 526 527 528 529 530 531 532 533 534 535 536 537 538 539 540 541 542 543 544 545 546 547 548 549 550 551 552 553 554 555 556 557 558 559 560 561 562 563 564 565 566 567 568 569 570 571 572 573 574 575 576 577 578 579 580 581 582 583 584 585 586 587 588 589 590 591 592 593 594 595 596 597 598 599 600 601 602 603 604 605 606 607 608 609 610 611 612 613 614 615 616 617 618 619 620 621 622 623 624 625 626 627 628 629 630 631 632 633 634 635 636 637 638 639 640 641 642 643 644 645 646 647 648 649 650 651 652 653 654 655 656 657 658 659 660 661 662 663 664 665 666 667 668 669 670 671 672 673 674 675 676 677 678 679 680 681 682 683 684 685 686 687 688 689 690 691 692 693 694 695 696 697 698 699 700 701 702 703 704 705 706 707 708 709 710 711 712 713 714 715 716 717 718 719 720 721 722 723 724 725 726 727 728 729 730 731 732 733 734 735 736 737 738 739 740 741 742 743 744 745 746 747 748 749 750 751 752 753 754 755 756 757 758 759 760 761 762 763 764 765 766 767 768 769 770 771 772 773 774 775 776 777 778 779 780 781 782 783 784 785 786 787 788 789 790 791 792 793 794 795 796 797 798 799 800 801 802 803 804 805 806 807 808 809 810 811 812 813 814 815 816 817 818 819 820 821 822 823 824 825 826 827 828 829 830 831 832 833 834 835 836 837 838 839 840 841 842 843 844 845 846 847 848 849 850 851 852 853 854 855 856 857 858 859 860 861 862 863 864 865 866 867 868 869 870 871 872 873 874 875 876 877 878 879 880 881 882 883 884 885 886 887 888 889 890 891 892 893 894 895 896 897 898 899 900 901 902 903 904 905 906 907 908 909 910 911 912 913 914 915 916 917 918 919 920 921 922 923 924 925 926 927 928 929 930 931 932 933 934 935 936 937 938 939 940 941 942 943 944 945 946 947 948 949 950 951 952 953 954 955 956 957 958 959 960 961 962 963 964 965 966 967 968 969 970 971 972 973 974 975 976 977 978 979 980 981 982 983 984 985 986 987 988 989 990 991 992 993 994 995 996 997 998 999 1000 1001 1002 1003 1004 1005 1006 1007 1008 1009 1010 1011 1012 1013 1014 1015 1016 1017 1018 1019 1020 1021 1022 1023 1024 1025 1026 1027 1028 1029 1030 1031 1032 1033 1034 1035 1036 1037 1038 1039 1040 1041 1042 1043 1044

Color: white color and colorism to yellowish gray

The first step in the process of the development of the new system is the identification of the requirements. This is done by the user and the system analyst. The next step is the design of the system. This is done by the system analyst. The third step is the implementation of the system. This is done by the programmer. The fourth step is the testing of the system. This is done by the user and the system analyst. The fifth step is the maintenance of the system. This is done by the user and the system analyst.

The first part of the paper discusses the importance of the structure of the organization in determining its performance. The second part of the paper discusses the importance of the culture of the organization in determining its performance.

[illegible]

water in contact with calcium carbonate when heated in a sealed tube produced dolomite. It is not uncommon that dolomite and calcite occur together in a single rock, thus indicating the possibility of their separate crystallization from a common solution.

Magnesite is not to be confused with other carbonates except that it more often shows crystal faces than the others.

Occurrence. Magnesite occurs in various localities near the base of the Silurian in the Adirondack region. It is also found in the Green Mountains, New York, and in the Adirondack region, New York. It is also found in the Adirondack region, New York, and in the Adirondack region, New York.

The magnesite occurring in the Adirondack region is a very pure variety, and is often found in large, well-developed crystals. It is also found in the Adirondack region, New York, and in the Adirondack region, New York.

For their crystals, magnesite is given here. Such are the crystals of magnesite in the Adirondack region, New York, and in the Adirondack region, New York.

The magnesite occurring in the Adirondack region is a very pure variety, and is often found in large, well-developed crystals. It is also found in the Adirondack region, New York, and in the Adirondack region, New York.

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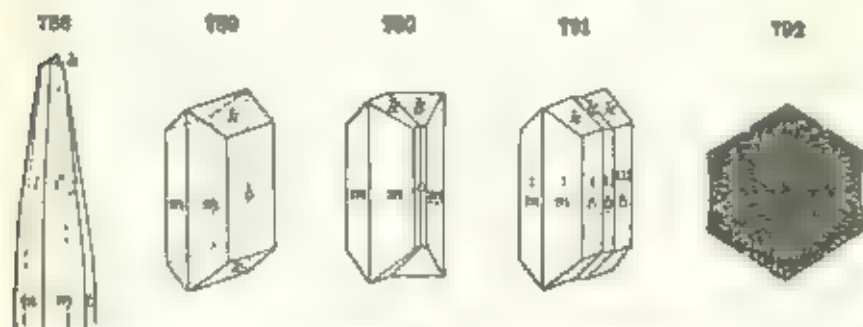
MAGNESITE

Monoclinic, $a = 0.8112$, $b = 0.411$, $c = 0.411$, $\beta = 72^\circ 36'$. Crystals rare, usually in small, prismatic forms, many massive granular or capable of very compact, earthy.

Color: white, yellowish, or grayish white, brown. Translucent to opaque. Lustre: vitreous to earthy. Fracture: flat to conchoidal. Hardness: $H = 3.5$, $G = 4.5$. Specific gravity: 2.9. Magnesite is a very pure variety of magnesite, and is often found in large, well-developed crystals. It is also found in the Adirondack region, New York, and in the Adirondack region, New York.

surfaces of fracture. Color white, also gray, yellow, green, and violet, streak uncolored. Transparent to translucent. Optically -. $Ax \parallel a(100)$, $Bx \perp c(001)$. Dispersion $\rho < \nu$ small. $2V = 18^\circ$, $\sigma = 1.530$, $\beta = 1.080$, $\gamma = 1.085$.

Comp. = Calcium carbonate, $CaCO_3$ = Carbon dioxide 44.0, lime 56.0 = 100. Some varieties contain a little strontium, others lead, and rarely zinc.



Aragonite is under ordinary conditions of temperature and pressure relatively unstable, changing to calcite, although usually the rate of change is very slow. Crystals of aragonite have been observed which have completely changed to calcite, examples of paracrystallization (see p. 358).

Var. = Ordinary. *a*. Crystallized in simple or compound crystals, the latter much the most common, often in radiating groups of acicular crystals. *b*. Columnar, also fine fibrous with silky luster. *c*. Massive.

Stromatolite or stromatolitic. Either compact or fibrous in structure, as with calcite. Stromatolites are distinct from *harshad* *Kohema*. *Conoidal*. In groupings of delicate interlacing and converging stems, of a snow white color as if looking a little like coral, often called *flow-form*. *Pisoidic*. Spherical concretions. *Terni variety* is a hard rock containing lead carbonate (to 16 per cent. from Tarnowitz in S. Boh., with $d = 2.99$ and from Postup, Austria). *Zephringite* is a calcareous sinter, probably aragonite, colored greenish white or sky blue with pink from Zephring, Nevada. *Nicholsonite* is a rock from near Leadville, Colorado and the Tintic District, Utah. The siliceous ones called *conchite* and *claystone* are apparently porous forms of aragonite.

Pyrit., etc. B.B. whitens and fuses to pyrexia, and sometimes, when containing strontium, imparts a more intense red color to the flame than lime. Otherwise reacts like calcite. When immersed in cold nitric solution it effervesces and dissolves for percents on boiling while some under like conditions remains uncolored or becomes blue on long heating (Mengen's reaction). This test is not applicable when the crystals are already colored or when the two varieties are mixed. The distinction can, however, be emphasized by further treatment with ammonium sulphide, when the basic barium carbonate deposited on the grains of aragonite is converted into a black sulphide, while under the same conditions barium carbonate remains gray.

Diff. Unlike calcite, from calcite by higher specific gravity and absence of rhombohedral cleavage from the solution, e.g., with the aid of a microscope in acid. Strontium and witherite are fusible, higher in specific gravity and give distinctive flames B.B. The rounded, later on frayed surfaces is to be noted.

Artif. Aragonite will form when solutions of calcium carbonate are evaporated at temperatures for a 50° to 100° , it will form at lower temperatures if the solution contains some sulphate or other substance if the carbonates of strontium or lead.

Obs. — Aragonite is much less common than calcite. It is formed under a much narrower range of conditions than calcite and being the less stable form, often changes to calcite with a change of surrounding conditions. It is formed through organic agencies, as a deposit from hot springs, and as a precipitate from saline solutions that contain sulphate. The most common repositories for aragonite are beds of gypsum, also beds of iron ore, especially with siderite, as in the Styrian mines, where it occurs in con-

nodal forms, and is called the ferric "flowers of iron." It is found in cavities of basalt and other lavas often associated with copper and iron sulphide, garnet, and malachite. It occurs also in the pearls layer of oyster shells and the shagreened surface of corals.

Some of the most important localities for this species are as follows: In Czechoslovakia at Herrgrotz and Trebany, north of Semany; Ban Kovacs, and Schmitz near Kiskisya in Slovakia; at Hrubá near Blatná in Bohemia; in lineaments crystals at Austria at Gams near Eisenack; in line crystals of the Bouda variety, at Leopoldsdorf near Vienna; in the mountains of Italy at Monte Rosa, Verone, and in fine thin crystals in the shape of drops at Sicily; especially at Argenta and Comana. In France the crystals are found at Beaumont, Auzan at Vertizon and Le de Meuse, and in twinned near Hues near Bayona on the sea. The minerals have been found from Arizona, Sonora, the most notable crystals being from hexagonal twin crystals at Mazua Province of Chihuahua. In England crystals of this mineral are found at Aston in the County of Northampton. At Copacabana, Bolivia, it occurs in twin crystals which are from time to time replaced by other crystals.

owns in California and in the States of Texas and Colorado. He is also
in the United States of America, in the States of Texas, California, Colo-
rado, Iowa, and at Santa Monica, California, in the United States of America, in the
States of California, New Mexico, and Arizona, at Bishop and near Tucson, in large six-
mile square tracts of land, in the States of California, Colorado.

Bromite. Anhydrous. $\text{Ba}(\text{BrO})_2$, nearly $\text{Ca}(\text{BrO})_2$. May contain small amounts of $\text{Fe}(\text{BrO})_2$. Freshly obtained from barite in a vacuum furnace at 1520-1550°C. It is a white, granular powder. It is soluble in water, forming a colorless solution. It is stable in air and water, but decomposes on heating to form barite and oxygen. It is used as a source of bromine in the laboratory.

WITHERTE

Orthorhombic. Axes $a \cdot b \cdot c = 0.6032 : 1 : 0.7302$. Crystals always repeated twins, simulating hexagonal pyramids, tw. p. $\{110\}$. Also massive columnar or granular.

Cleavage $h(110)$ dis. net. $m(110)$ imperfect. Fracture uneven. Brittle. $H = 4-4.7$. $G = 4.27-4.35$. Lustre vitreous, inclining to resinous on surfaces of fracture. Color white, yellowish, grayish. Streak white. Semi-transparent to transparent. Optically = Ax pl. ω_{10} Bx \perp (00). $2V = 10^\circ$. $\alpha = 1.529$. $\beta = 1.676$. $\gamma = 1.677$.

Comp. — Barium carbonate, BaCO_3 = Carbon dioxide 22.3, baryta 77.7
= 100.

Trans at 311° C to a hexagonal form and at 382° C to an isometric form.
Pyr, etc. RH fuses at 240 degs coloring the flame a wine green after 1 mon
from treatment. R is opacescens a thorax open cavity and is a seal with the m. Sol
the is to be by coloring up H and a few where very much dilute, given with su
phor with a few, the much is used for, acids

Diff. that is called by its high specific gravity; effervesces in acid green coloration of the flame. It is a carbonate of a bivalent metal.

[illegible]

In F. Gould's letter, references are made to a blood-letting machine, name plates with galena and North American fossils, and a fossil near Huxham. At the time he wrote this, it is larger than mineral and is a fossil. In Japan it is also a fossil, a fossilization of Pouter, 1870. In the fossil, a fossil found in the fossilized with the fossil in the fossil. The fossil is also reported from a fossilization with in the fossilization. The fossil is the fossil, the fossil, the fossil.

Use: A major source of barium compounds.

STRONTIANITE.

Orthorhombic. Axes a b $c = 0.6090$ 1 0.7236.
Crystals often acicular or acutely spear-shaped, like aragonite. Twins tw-
pl on {100} common, giving pseudo-hexagonal types. Also columnar, fibrous
and granular.

uncoated. Transparent to subtransparent. Optically -, Ax pl 2/010; Bx 1 circle. Dispersion $\rho > 1$; large $2V = 5^\circ 14'$. The axial angle becomes smaller both with shorter wave-lengths of light and with the lowering of the temperature, becoming uniaxial in extreme violet at 15°C ($\alpha = 1.894$, $\beta = 2.076$, $\gamma = 2.078$).

Comp. = Lead carbonate, PbO = Carbon dioxide 16.5, lead oxide 83.5 = 100

Pyre, etc. In the closed tube decrepitate, brown fumes evolve, turn a gray color, and at a higher temperature turn red, but when cooling down again the color turns red and these are easily, and in little yields, removed. Sublimation white, orange and with eff. very rare.

Diff. characterized by high species diversity and high biomass. Most birds are songbirds. Low abundance of large herbivores. (effects of forest type on bird diversity)

And change in the heat capacity can be by a new expression of a coordinate system in the x and y plane through a point (x_0, y_0) by the definition of a coordinate system on a lead plate.

Obs. Cerebrum is a small, soft, pinkish, fleshy organ. It is covered by a thin, yellowish, translucent membrane, the pia mater, which is continuous with the arachnoid. The surface of the cerebrum is covered by a thick, yellowish, fatty substance, the arachnoid, which is continuous with the pia mater. The cerebrum is divided into two halves, the left and right hemispheres, by a deep groove, the longitudinal fissure. The surface of the cerebrum is covered by a thick, yellowish, fatty substance, the arachnoid, which is continuous with the pia mater. The cerebrum is divided into two halves, the left and right hemispheres, by a deep groove, the longitudinal fissure.

[illegible][illegible]

Use. — An ore of lead.

BARYTOCALCITE

Monoclinic. Axes $a : b : c = 0.7717 : 1 : 0.0254$; $\beta = 73^\circ 52'$. In crystals the massive.

Chlorage $m=110$ perfect $\epsilon=0.01$ loss ϵ_0 . The three cleavage planes make angles with each other but are near those of the principal cleavage planes of calcite. Structurally it shows relations to calcite, aragonite and barite. The unit cell contains two molecules. $P=1.57$ is in even ϵ , ϵ is in odd ϵ . Brittle. $H=4-6$, $G=5.6-6.6$. Luster vitreous, sometimes resinous. Color white, gray, greenish or yellow. Streak white. Transparent to translucent. $D_{1000}^{20} = 2.95$, $D_{1500}^{20} = 1.525$, $D_{1600}^{20} = 1.684$, $D_{1800}^{20} = 1.686$. Ax. pl. \perp (010). λ λ axis $= +64^\circ$. $2V = 1^\circ$.

Comp. carbonate of barium and calcium, $\text{BaCO}_3 + \text{CaCO}_3$ = Carbon dioxide 24.6, water 54.5, lime 18.9 = 100

Fuse, etc. B.B. colors the flame with a wash green, and at a high temperature fuses in the thin edges and assumes a pale green color. The glass breaks a minute after spilling because it is not too hot to touch. **Flame coloration.** Intense salmon gives an abundant precipitate, BaSO_4 , with a few drops of sulphuric acid.

Salem and at Tsumeb near Otava, South West Africa. In fine crystals from Dundas in Tasmania, also from Broken Hill, New South Wales.

Northapatite $Mg(O, Na)(Fe, Na)$. Isometric orthohedra. $H = 3.5-4$ $G = 2.35$. White to yellowish gray, $n = 1.4$. Bases soluble. Presumably from same waters contain small amount of magnesium in solution. From Borax Lake, San Bernardino Co., California.

Tychite $Mg(O, 2Na)(Fe, Na)(SO_4)$. Isometric (tetrahedral) cube. $H = 3.5$ $G = 2.5$ $n = 1.41$. Easy to cleave. Very rare. From Borax Lake, San Bernardino Co., California, associated with northapatite.

B. Acid, Basic, and Hydrated Carbonates

Teschemacherite. Acid ammonium carbonate, HNH_4CO_3 . Orthorhombic. In yellowish to white crystals. $d_s = 4$ $H = 5$ $G = 1.45-1.50$. From guano deposits on the coast of Africa (Zanzibar Bay) and from the west coast of Patagonia, also on the Chancay Islands, Peru.

MALACHITE

Monoclinic. Axes $a : b : c = 0.8809 : 1 : 0.4012$ $\beta = 61^\circ 56'$

Crystals rarely distinct, usually slender, acicular prisms, $m = 110$ Δ $110 = 75^\circ 40'$, grouped in tufts and rosettes. Twins tw pl at 100° common. Commonly massive or fibrous, with surface botryoidal or spherulitic, and structure divergent, often delicately compact fibrous, and banded in color, frequently granular or earthy.

Cleavage c 100 perfect, b 010 less so. Fracture subconchoidal, uneven. Brittle. $H = 3.5-4$ $G = 3.9-4.03$. Luster of crystals adamantine, inclining to vitreous, of fibrous varieties more or less silky, often lil and earthy. Color bright green. Streak paler green. Translucent to sub-translucent to opaque. Typically $\alpha = 1.653$, $\beta = 1.873$, $\gamma = 1.909$. $2V = 43^\circ$. Ax pl (010). $X \Delta c$ axis = $+23^\circ 36'$. $X =$ nearly colorless, $Y =$ yellowish green, $Z =$ deep green.

Comp. Basic cupric carbonate, $CuCO_3 \cdot Cu(OH)_2 =$ Carbon dioxide 10.9, cupric oxide 71.9, water 8.2 = 100.

Cuprocyanite and *procuprocyanite* are names given to some bearing malachite-like minerals from Tsumeb near Otava, South West Africa. They are isomorphous. $2V = 92$ $n = 1.4$ n optically pronounced like those of malachite. The mineral is pure or nearly pure and may only be an altered or zoning malachite. See also page 520.

Pyrite, etc. In the chief place in which it occurs in water. B. H. luster at a coating the flame character gives no character in redness to metallic copper, with the flame reacts like cuprite. Soluble in acids with effervescence.

Dif. Chalcocite differs by green color and copper reactions B. H. differs from other cuprites by a green color and effervescence with acids.

Artf. Malachite has been formed artificially by heating precipitated copper carbonate with a solution of sodium carbonate for several days.

Obs. Malachite is a common ore of copper occurring in many of the ore shoots some of copper deposits, where it is associated with other ores. It is the product of their alteration. It is widespread in its occurrence and is more important because it can be concentrated. It has been found in large amounts at the following localities: The Ural Mts. near Yekaterinburg. In these is now a bed of malachite was exposed which yielded many tons of the mineral. The mass appeared at top of a hill and the bottom of the vein contained in some half a million gallons of the pure mineral. Most of the material was used for ornamental purposes. From Malakoff in the Ural Mts. a fine crystalline form from Bessmer near Sverdlovsk (Russia). From Chagay near Lyubimsk, Russia. In amount at Ileskovo and elsewhere. At Katanga in the Congo (Congo). In Northern Rhodesia at Ilwaco, M. near Tsumeb near Otava, South West Africa, and at San Bernardino, Cape Province, South Africa. In South Australia in the Largs district and at Wollaston.

2V = 53°. Ax. pl. 1/001. $K = a$ axis. From a coal mine at Nesquehoning, Schuylkill Co., Pennsylvania. See laurfordite, p. 531.

Naïon. Hydrous sodium carbonate, $\text{Na}_2\text{CO}_3 \cdot 9\text{H}_2\text{O}$. Occurring in nature only in solution, as in the soda lakes of Egypt, Nevada, California, etc., or mixed with the other sodium carbonates.

Pirssonite. $(\text{CaCO}_3, \text{Na}_2\text{CO}_3, 2\text{H}_2\text{O})$. In prismatic crystals, orthorhombic-hemimorphic. $H = 3$. $G = 2.58$. Easily fusible. Colorless to white. Optically $\gamma +$. $\alpha = 1.504$, $d = 1.509$, $\gamma = 1.575$. 2V = 35°. Ax. pl. 1/001. $Z = b$ axis. Borax Lake, San Bernardino Co., California.

GAY-LUSSITE

Monoclinic. Axes $a : b : c = 1.4597 : 1.4442 ; \beta = 78^\circ 27'$.

mm,	110 \wedge 110 = $113^\circ 10'$
ac,	011 \wedge 011 = $100^\circ 30'$
ma,	110 \wedge 011 = $45^\circ 21'$
rr,	112 \wedge 112 = $69^\circ 29'$

Crystals often elongated $\parallel a$ axis, also flattened wedge-shaped. Cleavage: (110) perfect, 001 rather difficult. Fracture conchoidal. Very brittle.

$H = 2-3$. $G = 1.93-1.95$. Luster vitreous. Color white, yellowish white. Streak uncolored to grayish. Translucent. Optically $-$. $\alpha = 1.444$, $\beta = 1.516$, $\gamma = 1.523$. 2V = 34° . Dispersion strong, $p < v$. Ax. pl. \perp (010). $Z \wedge c$ axis = 14° .

Comp. — Hydrous carbonate of calcium and sodium, $\text{CaCO}_3, \text{Na}_2\text{CO}_3, 5\text{H}_2\text{O}$ = Calcium carbonate 33.8, sodium carbonate 35.8, water 30.4 = 100.

Pyrr., etc. Heated in a closed tube decrepitates and becomes opaque. BB fuses easily to a white enamel, and on the flame strongly yellow. Changes in acids with a brisk effervescence, partly soluble in water and fuses to a fuming mass.

Obs. — Abundant at Layton near Mead, a Nevada lake, in crystals of green tint at the bottom of a small lake in a bed of clay, covering tons. Also abundant in Little Salt Lake, a brackish lake on the Carson Desert near Daguerre, Nevada. Deposited from the evaporation of the water. From Sweetwater Valley, Wyoming. Named after Gay-Lussac (the French chemist, 1778-1840).

Laurfordite. $\text{La}_2(\text{CO}_3)_2 \cdot 9\text{H}_2\text{O}$. In tabular orthorhombic crystals, also granular earthy. Cleavage 001, perfect. $H = 3$. $G = 2.005$. Optically H $-$ color grayish white to pink with wash. Optically $-$. $\alpha = 1.52$, $d = 1.587$, $\gamma = 1.613$. 2V = 62° . Ax. pl. 1/001. $K = c$ axis. Found coating urtic at the Helsingfors mine near Helsingfors, Västmanland, Sweden. At the San Juan ore bed, Alrich, Essex Co., New York, it is soluble in water. In Pennsylvanian rocks it is associated with the carbonate of the same name. Lehigh Co. as a mass of delicate pink crystals in the soil a few feet below the surface at Friedensburg.

TRONA. Urea.

Monoclinic. Axes $a : b : c = 2.8460 : 1 : 2.9700$. $\beta = 77^\circ 23'$.

ca,	001 \wedge 100 = $77^\circ 23'$
co,	001 \wedge 111 = $5^\circ 53'$
ac,	111 \wedge 111 = $47^\circ 35'$

In plates 1001, or elongated $\parallel b$ axis, often fibrous or columnar massive.

Cleavage. (100) perfect, (111), 001 in traces. Fracture uneven to subconchoidal. $H = 2.5-3$. $G = 2.11-2.14$. Luster vitreous, glistening.

Pyrosulphite. $\text{MgCO}_3 \cdot 5\text{Mg(OH)} \cdot 2\text{Fe(OH)} \cdot 4\text{H}_2\text{O}$ Hexagonal. Very slender individual crystals, sometimes showing hexagonal prisms and rhombohedra. In thin plates, colorless. Lustre glassy. Hardness 1.5. Specific gravity 1.4. Cleavage perfect, basal. Fracture conchoidal. Streak white. Soluble in water. Occurs at Poughkeepsie, New York, and at the Mine Hill, North Carolina. Also at the Mine Hill, North Carolina. (Feldspar).

Pyrosulphite. $\text{MgCO}_3 \cdot 5\text{Mg(OH)} \cdot 2\text{Fe(OH)} \cdot 4\text{H}_2\text{O}$ Hexagonal. Muscovite. In scales. Perfect cleavage. Hardness 1.5. Specific gravity 1.4. Cleavage perfect, basal. Fracture conchoidal. Streak white. Soluble in water. Occurs at Poughkeepsie, New York, and at the Mine Hill, North Carolina. (Feldspar).

Sulphite. $\text{MgCO}_3 \cdot \text{Mg(OH)} \cdot 2\text{Fe(OH)} \cdot 4\text{H}_2\text{O}$ Hexagonal. Muscovite. In scales. Perfect cleavage. Hardness 1.5. Specific gravity 1.4. Cleavage perfect, basal. Fracture conchoidal. Streak white. Soluble in water. Occurs at Poughkeepsie, New York, and at the Mine Hill, North Carolina. (Feldspar).

Zirconite. Emerald Green. $\text{ZrO}_2 \cdot \text{SiO}_2 \cdot 2\text{H}_2\text{O}$ Hexagonal. In many colors. Hardness 7.5. Specific gravity 4.7. Cleavage perfect, basal. Fracture conchoidal. Streak white. Soluble in water. Occurs at Poughkeepsie, New York, and at the Mine Hill, North Carolina. (Feldspar).

Zirconite. Emerald Green. $\text{ZrO}_2 \cdot \text{SiO}_2 \cdot 2\text{H}_2\text{O}$ Hexagonal. In many colors. Hardness 7.5. Specific gravity 4.7. Cleavage perfect, basal. Fracture conchoidal. Streak white. Soluble in water. Occurs at Poughkeepsie, New York, and at the Mine Hill, North Carolina. (Feldspar).

Tenacity. $\text{ZrO}_2 \cdot \text{SiO}_2 \cdot 2\text{H}_2\text{O}$ Hexagonal. In many colors. Hardness 7.5. Specific gravity 4.7. Cleavage perfect, basal. Fracture conchoidal. Streak white. Soluble in water. Occurs at Poughkeepsie, New York, and at the Mine Hill, North Carolina. (Feldspar).

Bastnaesite. $\text{Ce}_2\text{O}_3 \cdot \text{SiO}_2 \cdot 2\text{H}_2\text{O}$ Hexagonal. In many colors. Hardness 7.5. Specific gravity 4.7. Cleavage perfect, basal. Fracture conchoidal. Streak white. Soluble in water. Occurs at Poughkeepsie, New York, and at the Mine Hill, North Carolina. (Feldspar).

Bastnaesite. $\text{Ce}_2\text{O}_3 \cdot \text{SiO}_2 \cdot 2\text{H}_2\text{O}$ Hexagonal. In many colors. Hardness 7.5. Specific gravity 4.7. Cleavage perfect, basal. Fracture conchoidal. Streak white. Soluble in water. Occurs at Poughkeepsie, New York, and at the Mine Hill, North Carolina. (Feldspar).

Bastnaesite. $\text{Ce}_2\text{O}_3 \cdot \text{SiO}_2 \cdot 2\text{H}_2\text{O}$ Hexagonal. In many colors. Hardness 7.5. Specific gravity 4.7. Cleavage perfect, basal. Fracture conchoidal. Streak white. Soluble in water. Occurs at Poughkeepsie, New York, and at the Mine Hill, North Carolina. (Feldspar).

Bastnaesite. $\text{Ce}_2\text{O}_3 \cdot \text{SiO}_2 \cdot 2\text{H}_2\text{O}$ Hexagonal. In many colors. Hardness 7.5. Specific gravity 4.7. Cleavage perfect, basal. Fracture conchoidal. Streak white. Soluble in water. Occurs at Poughkeepsie, New York, and at the Mine Hill, North Carolina. (Feldspar).

Oxygen Salts

2. SILICATES

The silicates comprise the largest family group among minerals. They show a wide range of composition, and are found in a very compact in character. However, they have a very high specific gravity and are found in a wide range of colors.

mental facts concerning their atomic structure and thrown much light upon the intricate problems of their composition. It is now well established that the fundamental structural unit of all silicates has a tetrahedral shape with four oxygen atoms surrounding each silicon atom. If these SiO_4 groups may be linked together in various ways to form a lattice or extended system. In the crystalline silicates these SiO_4 groups occur independently with regard to the other elements present, as in silicic acid, such as a silicic acid, a carbonate, etc. In other types, however, the SiO_4 groups are linked together by having one or more atoms of oxygen shared in common by the adjoining groups. If two adjacent SiO_4 groups have one atom of oxygen in common, they are groups with single bonds as with Si_2O_7 , Si_2O_5 . Such may occur further, so SiO_4 groups may form chains in which two oxygen atoms of two adjacent groups are held in common. Single chains of this type with a composition corresponding to SiO_3 occur in pyroxene. In addition two such chains are linked together giving a composition represented by Si_2O_6 . Such chains may be further linked together to form a sheet, the oxygen shared to be characteristic of the sheet, with a composition of Si_2O_4 . Again the linking of the silicon-oxygen chains may take place so as to give rise to a three-dimensional network. Such a grouping is characteristic of the different forms of silica, quartz, tridymite, etc., and by supposing a partial replacement of silicon by aluminum in the chains and network may be obtained in which hydrogen atoms can be introduced. This latter structure is supposed to be characteristic of the zeolites, where metal atoms may be artfully substituted for each other and the water content varied without disturbing the fundamental structure. In these various consequences of structure, hydrogen atoms are placed in such ways as to bind the whole structure together. It has been known that where monovalent substitution takes place the number of hydrogen atoms inserting to and with remains constant for each unit, and of the structure. Variations in composition may involve the substitution of Si by Al , of Al , Mg , and Fe by each other, of Na by Ca , etc. A general statement by Bragg* is that a silicate should be regarded as a structure having a constant number of oxygen atoms in the unit with a constant number of places for metal and where which can be filled by these elements in varying proportions consistent with a balance between valencies.

It can be seen that this view of the structure of the silicates largely does away with the necessary assumption of the existence of distinct silicate and aluminosilicates and water groups, the usual method of the classification of the silicates. Such a study of the silicates is however, very far from complete at the time has not yet arrived where it is needed research on extension needed. Therefore in this study on the silicates, a classification of the silicates has been kept, but where possible, as far as possible, the new facts of structure and relations between species have been introduced in their appropriate places.

The silicates are a very structurally diverse group, in part because of the degrees and the amorphous states, etc. Furthermore, a large number of the silicates used more or less water, geologically, and biologically, and it is known that they are therefore, some regarded as hydrous or acid silicates. There is a difference between the strictly anhydrous and the hydrous silicates, at least as it is known, since with many species which yield water upon heating the process is a

* The substance of these paragraphs has been quoted and modified by permission of the author. The structure is taken from W. L. Bragg, *Zell. für. 74*, 247, 248.

the elements forming the water is as yet uncertain. Furthermore in the cases of several groups the strict arrangement must be deviated from, since the reaction of the species is best exhibited by introducing the related hydrous species immediately after the others.

The chapter closes with a section including the Titanates, Silico-titanates, Titan-niobates, etc. which connect the Silicates with the Niobates and Tantalates. Some Titanates have already been included among the Oxides.

Section A. Chiefly Anhydrous Silicates

- I. Disilicates, Polysilicates
- II. Metasilicates
- III. Orthosilicates
- IV. Subsilicates

The **DISILICATES**, RSi_2O_5 , are salts of disilicic acid, $H_2Si_2O_5$, and have an oxygen ratio of 2 to 1, as seen when the formula is written after the diatomic method, $RO \cdot 2SiO_2$.

The **POLYSILICATES**, RSi_nO_{3n} , are salts of polysilicic acid, $H_2Si_nO_{3n}$, and have an oxygen ratio of 3 to 1, as seen in $2RO \cdot 3SiO_2$.

The **METASILICATES**, $RSiO_3$, are salts of metasilicic acid, H_2SiO_3 , and have an oxygen ratio of 2 to 1. They have hence been called *metasilicates*.

The **ORTHO-SILICATES**, $RSiO_2$, are salts of orthosilicic acid, H_4SiO_4 , and have an oxygen ratio of 2 to 1. They have hence been called *orthosilicates*. The majority of the silicates fall into one of the last two groups.

Furthermore there are a number of species characterized by an oxygen ratio of less than 2 to 1, e.g. 3 to 4, 2 to 3, etc. These basic species are grouped as **SUBSILICATES**. Their true position is often in doubt in those cases that are policy to be regarded as basic salts belonging to one of the other groups.

The above classification cannot, however, be carried through strictly since there are many species which do not exactly conform to any one of the groups named, and often the true interpretation of the composition is doubtful. Furthermore within the limits of a single group of species connected closely in their essential characters there may be a wide variation in the proportion of the anionic element. Thus the trisilicic feldspars, placed among the polysilicates, range from the true polysilicate, $NaAlSi_3O_8$, to an orthosilicate, $Ca_2Al_2Si_2O_{10}$, with many intermediate compounds, regarded as polymorphic mixtures of these extremes. Similarly of the scapolite group, which however is included among the orthosilicates, since the majority of the compounds observed approximate to that type. The micro form another example.

I. Disilicates, RSi_2O_5 . Polysilicates, RSi_nO_{3n}

PETALITE.

Monoclinic. $a:b:c = 1.153:1:0.744$. $\beta = 67^\circ 34'$. Crystals rare (concentric). Luster massive foliated conchoidal (petalite).

Transparency (100) perfect (200) easy, (300) difficult and imperfect fracture imperfectly conchoidal. Brachy $H = 6.65$. $G = 2.49-2.46$. Luster varies from (100) pearly. Colorless, white, gray, occasionally reddish or greenish white. Streak uncolored. Transparent to translucent. Optically $+$. $\alpha = 1.504$. $\beta = 1.410$. $\gamma = 1.516$. $2V = 83^\circ$. Ax pt 1 (010). $X \wedge a$ axis = $2^\circ-8^\circ$.

Comp. — $\text{LiAl}(\text{Si}_2\text{O}_6)_2$ or $\text{Li}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 8\text{SiO}_2 = \text{Silica } 78.4, \text{ alumina } 16.7, \text{ lithia, } 4.9 = 100.$

When heated becomes biaxial between 1000 and 1400° and isotropic at 1500°.
Pr., etc. — Heated crystals show phosphorescent light. R.B. fuses easily at 5 on (gives the reaction for silica). With borax forms a clear, colorless glass. Not acted on by acids.

Obs. — Pectolite occurs at the same place on the island of Ådö, State of Stockholm, Sweden, as Epidymite, tourmaline, spodumene and garnet in the same rocks. In the United States, at Fiddler's Green, Massachusetts, with tourmaline, at Deer Island, Maine, with spodumene in granite. The same petiole as that of pectolite, being identical in its cleavage.

Militarite $(\text{K}_2\text{Al}_2\text{Si}_2\text{O}_{10})_2 \cdot \text{H}_2\text{O}$ In hexagonal prisms. Mixed with epidymite. Thin sections showing no color when examined in thin sections. On heating crystals at 150° a reaction with silica. **Indices** — $n_x = 1.52, n_y = 1.52, n_z = 1.52, n_{xy} = 1.52, n_{yz} = 1.52, n_{zx} = 1.52, n_{xy} = 1.52, n_{yz} = 1.52, n_{zx} = 1.52$. From Val d'Aoste, Switzerland.

Epidymite $(\text{HNaAlSi}_2\text{O}_6)_2$. Muscovite. In white glassy twinned crystals, tabular in habit, 001 lamellar, splitting on 001 cleavage. $H = 5.5, C_1 = 2.55$. Very easily shows a lamellar structure in thin sections. $H = 5.5, C_1 = 2.55$. Easy to cleave. $H = 5.5, C_1 = 2.55$. $Z = 0.015$. Distinct cleavage. $H = 5.5, C_1 = 2.55$. From Narvik, Norway.

Epidymite. Same composition as epidymite. Orthorhombic. Tabular. 001 cleavage. $H = 5.5, C_1 = 2.55$. Easily soluble. $H = 5.5, C_1 = 2.55$. From Narvik, Norway.

Lafite — $\text{Na}_2\text{Al}_2\text{Si}_2\text{O}_{10} \cdot \text{H}_2\text{O}$. Colorless hexagonal prisms. Prismatic cleavage. $H = 5.5, C_1 = 2.55$. From deasy cavities in nepheline veins at Narvik, Greenland.

Feldspar Group

a. Monoclinic Section

		a	b	c	B'
Orthoclase	KAlSi_3O_8	0.6585	1	0.5534	116° 3'
Soda-Orthoclase	$\left\{ \begin{array}{l} (\text{K}, \text{Na})\text{AlSi}_3\text{O}_8 \\ (\text{Na}, \text{K})\text{AlSi}_3\text{O}_8 \end{array} \right.$				
Hyalophane	$(\text{K}, \text{Ba})\text{Al}_2\text{Si}_2\text{O}_6$	0.6584	1	0.5512	115° 35'
Caesal	$\text{BaAl}_2\text{Si}_2\text{O}_6$	0.657	1	0.554	115° 2'

b. Triclinic Section

Microcline	KAlSi_3O_8
Soda-microcline	$(\text{K}, \text{Na})\text{AlSi}_3\text{O}_8$
Anorthoclase	$(\text{Na}, \text{K})\text{AlSi}_3\text{O}_8$

Albite-anorthite Series. *Trigonal Feldspars*

		a	b	c	α	β	γ
Albite	$\text{NaAlSi}_3\text{O}_8$	0.6335	1	0.5577	91° 3'	116° 29'	88° 9'
Oligoclase		0.6321	1	0.5524	93° 4'	116° 23'	90° 5'
Andesine	$\left(\frac{n\text{NaAlSi}_3\text{O}_8}{m(\text{NaAl}_2\text{Si}_2\text{O}_6)} \right)$	0.6357	1	0.5524	93° 23'	116° 29'	89° 59'
Labradorite		0.6377	1	0.5547	93° 31'	116° 3'	89° 54'
Bytownite					93° 22'	116° 0'	90° 41'
Anorthite	$\text{CaAl}_2\text{Si}_2\text{O}_6$	0.6347	1	0.5501	93° 13'	115° 55'	91° 12'

The general characters of the species belonging in the FELDSPAR GROUP are as follows:

1. *Crystallization* in the monoclinic or triclinic systems, the crystals of the different species assuming each other closely in angle in general habit, and in methods of twinning. The principal angle in all cases differs but a few degrees from 60° and 120° . X-ray study of the feldspar group shows the close similarity in structure that exists between its members. Four molecules are contained in the unit cell.

2. *Cleavage* in two similar directions parallel to the base $c(001)$ and clinopinacoid or brachypinacoid, $b(010)$ inclined at an angle of 90° or nearly 90° . 3. *Hardness* between 6 and 6.5. 4. *Specific Gravity* varying between 2.5 and 2.9, and *density* between 2.65 and 2.75. 5. *Color* white or pale shades of yellow, red or green (less common) or dark. 6. In composition silicates of aluminum with either potassium, sodium, or calcium and rarely barium, while magnesium and iron are always absent. Furthermore, besides the several distinct species there are many intermixed compounds having a certain independence of character and yet connected with each other by innumerable gradations: all the members of the series showing a close relationship not only in composition but also in crystal habit and physical characters.

The species of the feldspar group are classified, first as to form, and second with reference to composition. The *monoclinic* species include (see above): ORTHOCLASE, potassic feldspar, and SODA-ORTHOCLASE, potassium-sodium feldspar; also HYALOPHANE and CELSIAN, barium feldspars.

The *triclinic* species include: MICROCLINE and ANORTHOCLASE, potassium-sodium feldspars, ALBITE, sodium feldspar, ANORTHITE, calcium feldspar.

Also intermediate between albite and anorthite the isomorphous subspecies, sodium-calcium or calcium-sodium feldspars. OLIGOCLASE, ANDRINE, LABRADORITE, BYTOWNITE.

a. Monoclinic Section

ORTHOCLASE.

Monoclinic Axes $a = 0.6585$ $b = 0.5554$, $\beta = 63^\circ 57'$

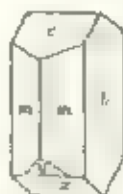
<i>mm</i> ¹¹⁰	$110 \wedge \bar{1}\bar{1}0 = 81^\circ 13'$
<i>ax</i> ¹¹⁰	$110 \wedge 140 = 58^\circ 48'$
<i>az</i> ¹⁰¹	$101 \wedge \bar{1}01 = 40^\circ 10'$
<i>cy</i> ⁰⁰¹	$001 \wedge 201 = 80^\circ 16'$

<i>cr</i> ⁰⁰¹	$001 \wedge 021 = 44^\circ 56'$
<i>na</i> ¹¹²	$112 \wedge \bar{2}1 = 30^\circ 53'$
<i>cm</i> ¹⁰	$10 \wedge 10 = 67^\circ 47'$
<i>c</i> ⁰⁰¹	$001 \wedge 111 = 65^\circ 14'$

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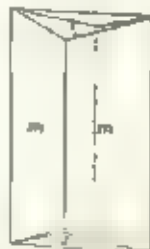
803



804

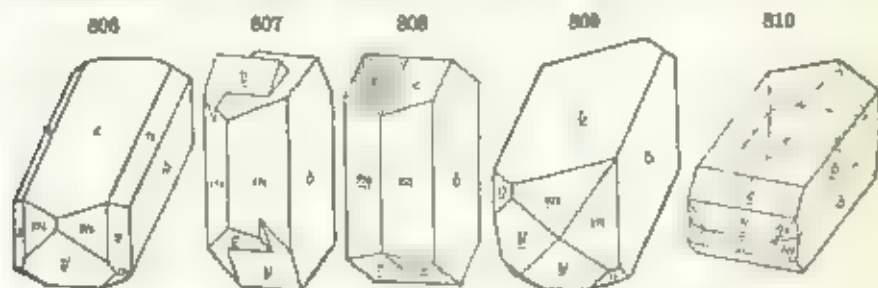


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Twins: (a) parallel to (001) , or (b) along c , the common *Carlsbad* twin, either of irregular penetration (Fig. 807) or contact type (the latter usually with $b(010)$ as composition-face, often seen (Fig. 808) with $c(001)$ and $x(101)$,

nearly in a plane, but to be distinguished by luster, cleavage, etc. (2) $\pi(021)$, the *Baxena* twins forming nearly square prisms (Fig. 800), since $cn = 44^\circ 56'$, and hence $\alpha = 89^\circ 53'$ often repeated as fourings. Fig. 473, p. 192), also n square prisms, elongated a axis. (3) $\epsilon(001)$, the *Manebach* twins (Fig. 810), usually contact-twins with c as composition face. Also other rarer laws.



Crystals often prismatic c axis, sometimes orthorhombic in aspect (Fig. 805 since $c(001)$ and $r(101)$ are inclined at nearly equal angles to the vertical axis, also elongated a axis (Fig. 806 with $b(010)$ and $c(001)$ nearly equally developed, also thin tabular $b(010)$, rarely tabular $a(100)$, a face not often observed. Often massive coarsely cleavable to granular, sometimes lamellar. Also compact crypto-crystalline and flint-like or Jasper-like.

Cleavage (001) perfect, (010) somewhat less so, prismatic $m(110)$ imperfect, but usually more distinct parallel to one prismatic face than to the other. Parting sometimes distinct parallel to $a(100)$, also to a hemi-orthorhombic one inclined a few degrees to the orthoprismatic, this may produce a satin-like luster or semilar $p(275)$ or later also often present when the parting is not distinct. Fracture conchoidal to uneven. Brittle. $H = 6$. $G = 2.56$ (anhydrous) $2.57-2.58$ (oxidized). Luster vitreous, on $c(001)$ often pearly. Colors, white, pale yellow and flesh-red common, gray, rarely green. Streak uncolored.

For adularia, $\alpha = 1.519$, $\beta = 1.523$, $\gamma = 1.525$. Slightly different for sandstone. In adularia the axial plane $(a \perp c(100))$ with $Z = b$ axis, X inclined only a few degrees to a axis ($+3^\circ$ to 7° cf. Fig. 811) or in varieties rich in Na $q(0)$ from 10° to 12° . Axial angle variable. Usually $2V = 70^\circ$ to 75° . When adularia is heated the axial angle diminishes becoming 0° between 600° and 800° C. Beyond that point the axial plane becomes (010) . Sandstone has this orientation for the axial plane with a small value for $2V$. Dispersion $\rho > \nu$, horizontal, strongly marked, or inclined, according to position of axial plane. Optically —

Comp. A silicate of aluminum and potassium, $KAlSi_3O_8$ or $K_2O \cdot Al_2O_3 \cdot 6SiO_2$ — Silica 64.7, alumina 18.4, potash 16.9 = 100. Sodium is often also present, replacing part of the potassium, and sometimes exceeds it in amount, these varieties are embraced under the name soda-orthoclase (the name *barbertite* has been proposed for the monoclinic



Full (1953) argued by its crystals the same as the two deep agree at right angles.

of the first order — hence lower than light and by the distinct cleavage.

due to alteration from weathering, the

$\frac{1}{n} \sum_{i=1}^n x_i = \bar{x}$

$$= 7.5 \times 10^{-11} \text{ m}^2 \text{ s}^{-1} \quad \text{for } T = 10^\circ \text{C}$$

... ..

$\frac{1}{2} \times \frac{1}{2} = \frac{1}{4}$

1991 12/20 21:00

Chlorophyll

...the

On the future of being the first to see the world in 7-10 years, the

[illegible]

1. The first step is to identify the problem or question that needs to be answered. This involves understanding the context and the specific requirements of the task.

1. The first step is to identify the key components of the system. This involves understanding the hardware and software involved, as well as the data flow and the roles of the various components.

[illegible]

1. $\frac{1}{2} \times \frac{1}{2} = \frac{1}{4}$

On 3.1.74, a letter from the Ministry of Health, London, was received, dated 28.12.73, regarding the above matter.

now we are getting the next revision of the book - now up here it is the

[Faint handwritten notes at the bottom of the page]

1. The first part of the report is a general statement of the purpose of the study and the scope of the work.

The first part of the paper is devoted to the study of the asymptotic behavior of the solutions of the system (1.1) as $\epsilon \rightarrow 0$. In the second part, we study the asymptotic behavior of the solutions of the system (1.1) as $\epsilon \rightarrow 0$.

$$P_{\text{eff}} = \frac{P}{1 + \frac{\alpha}{\beta} \left(\frac{P}{P_0} \right)^n}$$

$\frac{1}{2} \times \frac{1}{2} = \frac{1}{4}$

[illegible]
$$y = \frac{1}{2} \left(\frac{1}{\sqrt{1-x^2}} + \frac{1}{\sqrt{1-y^2}} \right) \quad \text{and} \quad \frac{1}{\sqrt{1-x^2}} = \frac{1}{\sqrt{1-y^2}} \quad \text{if} \quad x = y$$

5. 1954. 1955. 1956. 1957. 1958. 1959. 1960. 1961. 1962. 1963. 1964. 1965. 1966. 1967. 1968. 1969. 1970. 1971. 1972. 1973. 1974. 1975. 1976. 1977. 1978. 1979. 1980. 1981. 1982. 1983. 1984. 1985. 1986. 1987. 1988. 1989. 1990. 1991. 1992. 1993. 1994. 1995. 1996. 1997. 1998. 1999. 2000. 2001. 2002. 2003. 2004. 2005. 2006. 2007. 2008. 2009. 2010. 2011. 2012. 2013. 2014. 2015. 2016. 2017. 2018. 2019. 2020. 2021. 2022. 2023. 2024. 2025. 2026. 2027. 2028. 2029. 2030. 2031. 2032. 2033. 2034. 2035. 2036. 2037. 2038. 2039. 2040. 2041. 2042. 2043. 2044. 2045. 2046. 2047. 2048. 2049. 2050. 2051. 2052. 2053. 2054. 2055. 2056. 2057. 2058. 2059. 2060. 2061. 2062. 2063. 2064. 2065. 2066. 2067. 2068. 2069. 2070. 2071. 2072. 2073. 2074. 2075. 2076. 2077. 2078. 2079. 2080. 2081. 2082. 2083. 2084. 2085. 2086. 2087. 2088. 2089. 2090. 2091. 2092. 2093. 2094. 2095. 2096. 2097. 2098. 2099. 2100. 2101. 2102. 2103. 2104. 2105. 2106. 2107. 2108. 2109. 2110. 2111. 2112. 2113. 2114. 2115. 2116. 2117. 2118. 2119. 2120. 2121. 2122. 2123. 2124. 2125. 2126. 2127. 2128. 2129. 2130. 2131. 2132. 2133. 2134. 2135. 2136. 2137. 2138. 2139. 2140. 2141. 2142. 2143. 2144. 2145. 2146. 2147. 2148. 2149. 2150. 2151. 2152. 2153. 2154. 2155. 2156. 2157. 2158. 2159. 2160. 2161. 2162. 2163. 2164. 2165. 2166. 2167. 2168. 2169. 2170. 2171. 2172. 2173. 2174. 2175. 2176. 2177. 2178. 2179. 2180. 2181. 2182. 2183. 2184. 2185. 2186. 2187. 2188. 2189. 2190. 2191. 2192. 2193. 2194. 2195. 2196. 2197. 2198. 2199. 2200. 2201. 2202. 2203. 2204. 2205. 2206. 2207. 2208. 2209. 2210. 2211. 2212. 2213. 2214. 2215. 2216. 2217. 2218. 2219. 2220. 2221. 2222. 2223. 2224. 2225. 2226. 2227. 2228. 2229. 2230. 2231. 2232. 2233. 2234. 2235. 2236. 2237. 2238. 2239. 2240. 2241. 2242. 2243. 2244. 2245. 2246. 2247. 2248. 2249. 2250. 2251. 2252. 2253. 2254. 2255. 2256. 2257. 2258. 2259. 2260. 2261. 2262. 2263. 2264. 2265. 2266. 2267. 2268. 2269. 2270. 2271. 2272. 2273. 2274. 2275. 2276. 2277. 2278. 2279. 2280. 2281. 2282. 2283. 2284. 2285. 2286. 2287. 2288. 2289. 2290. 2291. 2292. 2293. 2294. 2295. 2296. 2297. 2298. 2299. 2300. 2301. 2302. 2303. 2304. 2305. 2306. 2307. 2308. 2309. 2310. 2311. 2312. 2313. 2314. 2315. 2316. 2317. 2318. 2319. 2320. 2321. 2322. 2323. 2324. 2325. 2326. 2327. 2328. 2329. 2330. 2331. 2332. 2333. 2334. 2335. 2336. 2337. 2338. 2339. 2340. 2341. 2342. 2343. 2344. 2345. 2346. 2347. 2348. 2349. 2350. 2351. 2352. 2353. 2354. 2355. 2356. 2357. 2358. 2359. 2360. 2361. 2362. 2363. 2364. 2365. 2366. 2367. 2368. 2369. 2370. 2371. 2372. 2373. 2374. 2375. 2376. 2377. 2378. 2379. 2380. 2381. 2382. 2383. 2384. 2385. 2386. 2387. 2388. 2389. 2390. 2391. 2392. 2393. 2394. 2395. 2396. 2397. 2398. 2399. 2400. 2401. 2402. 2403. 2404. 2405. 2406. 2407. 2408. 2409. 2410. 2411. 2412. 2413. 2414. 2415. 2416. 2417. 2418. 2419. 2420. 2421. 2422. 2423. 2424. 2425. 2426. 2427. 2428. 2429. 2430. 2431. 2432. 2433. 2434. 2435. 2436. 2437. 2438. 2439. 2440. 2441. 2442. 2443. 2444. 2445. 2446. 2447. 2448. 2449. 2450. 2451. 2452. 2453. 2454. 2455. 2456. 2457. 2458. 2459. 2460. 2461. 2462. 2463. 2464. 2465. 2466. 2467. 2468. 2469. 2470. 2471. 2472. 2473. 2474. 2475. 2476. 2477. 2478. 2479. 2480. 2481. 2482. 2483. 2484. 2485. 2486. 2487. 2488. 2489. 2490. 2491. 2492. 2493. 2494. 2495. 2496. 2497. 2498. 2499. 2500. 2501. 2502. 2503. 2504. 2505. 2506. 2507. 2508. 2509. 2510. 2511. 2512. 2513. 2514. 2515. 2516. 2517. 2518. 2519. 2520. 2521. 2522. 2523. 2524. 2525. 2526. 2527. 2528. 2529. 2530. 2531. 2532. 2533. 2534. 2535. 2536. 2537. 2538. 2539. 2540. 2541. 2542. 2543. 2544. 2545. 2546. 2547. 2548. 2549. 2550. 2551. 2552. 2553. 2554. 2555. 2556. 2557. 2558. 2559. 2560. 2561. 2562. 2563. 2564. 2565. 2566. 2567. 2568. 2569. 2570. 2571. 2572. 2573. 2574. 2575. 2576. 2577. 2578. 2579. 2580. 2581. 2582. 2583. 2584. 2585. 2586. 2587. 2588. 2589. 2590. 2591. 2592. 2593. 2594. 2595. 2596. 2597. 2598. 2599. 2600. 2601. 2602. 2603. 2604. 2605. 2606. 2607. 2608. 2609. 2610. 2611. 2612. 2613. 2614. 2615. 2616. 2617. 2618. 2619. 2620. 2621. 2622. 2623. 2624. 2625. 2626. 2627. 2628. 2629. 2630. 2631. 2632. 2633. 2634. 2635.

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For the purpose of this study, we used the following definitions:

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конституции, и в то время (тогда) Митч считал, что Дуглас и

Use. — In the manufacture of porcelain, both in the body of the ware and in the glaze on its surface.

TEXTURE. As first described, a flesh-red aventurine feldspar from Perth, Ontario, Canada, called a *microcline*, but shown by Lecharlier to consist of interlocking orthoclase and albite. Many mineral occurrences have since been noted, as was those in which the fine and sharp cleavage is interlaminate; the other named microcline with its characteristic perthite. This is true in part of the original perthite. When the structure is somewhat different with the help of the microscope it is called *microperthite*. Brögger has investigated and by the microscope of Norway has also shown that quartz characterised by a marked texture, he assumes the existence of an extremely fine intergrowth of albite and orthoclase (1911), not however due to the microcline *microperthite* but controlled by secondary patches of perthite (1900 or 30) which is probably to be explained as due to diffusion of feldspar. X-ray study has also shown the orthoclase at high temperatures may break up or strain into other feldspar molecules, albite, and at these temperatures seem to possess the same interlaminate texture as orthoclase. They may however unite in combinations that result, and he therefore has no less than six separate albite-orthoclase microstructures. This accounts for the intimate microgrowth of different feldspars shown in the perthites.

Hyalophane. — A hasten-bearing actinolite orthoclase. K-feldspar with $\text{Ba}(\text{Si}_2\text{O}_6)_2$ in which the hasten molecule is always hasten. In crystals are also hasten in habit (Fig. 545, p. 546), also hasten. $H = 6-6.5$, $G = 2.565-2.567$ (1911), $\alpha = 1.42$, $\beta = 1.511$, $\gamma = 1.547$ for a mixture containing 70 per cent $\text{Ba}(\text{Si}_2\text{O}_6)_2$. $Ax \parallel c$, $Z = b$ axis, $X \perp a$ axis from 0° to 90° . In crystals a gradual change in habit is seen, the hasten molecule being more or less absent in the hastenite variety, which is a form from veins of the hastenite zone at the hastenite in the hastenite mine, Vermont, also at the hastenite mine Oregon, in Oregon. Noted at Franklin, New Jersey.

Celsian. — $\text{Ba}_2\text{Si}_2\text{O}_7$, similar in composition to orthoclase, but containing barium instead of calcium. Microcline. In crystals showing a number of forms (twinned according to Carlsbad, Manheim and Baveno laws). $H = 6-6.5$, $G = 2.567$ (1911), $\alpha = 1.544$, $\beta = 1.506$, $\gamma = 1.544$, $2V = 88^\circ$. $Ax \parallel c$, $Z \perp c$ axis = 28° . From Jämsberg, in Norrbotten district, Vermeland, Sweden. No other hastenite occurrence given to us at present of celsian and orthoclase. Paracelsian from the same locality, Tonn valley, Piedmont, Italy, is the same species.

B. Triclinic Section

MICROCLINE

Triclinic. Near orthoclase in angles and habit, but the angle $bc(010)A(001) =$ about $89-90^\circ$. Twins have rhombic, also polyhedral twinning according to the albite law, perthite laws

814



on $c(001)$ sometimes pearly. Color white to pale cream-yellow also red, green. Transparent to translucent. Optically — $Ax \parallel c$ nearly perpendicular $82^\circ-84^\circ$, $b \perp b(010)$, Z inclined $15^\circ-26^\circ$ to a normal to $b(010)$. Dispersion $\rho < \nu$ about Z . Extinction-angle on $c(001)$, $+15^\circ-30^\circ$, on $b(010)$, $+5^\circ-6^\circ$ (Fig. 819, p. 542). $\alpha = 1.518$, $\beta = 1.522$, $\gamma = 1.525$. $2V = 83^\circ$.

Tschermak first established the isomorphous relations between these two molecules. X-ray study has shown an identity of structure throughout the series. The sodium and calcium atoms, on the one hand, and the magnesium and aluminum atoms, on the other, may replace each other in the structure. Various names have been given to minerals falling in certain positions in the isomorphous series. They are given below with the approximate range in composition commonly assigned to each.

| | Albite Molecule | Anorthite Molecule |
|-------------|--------------------|--------------------|
| ALBITE | 100 to 90 per cent | 0 to 10 per cent |
| OLIGOCLASE | 90 to 70 per cent | 10 to 30 per cent |
| ANDESINE | 70 to 50 per cent | 30 to 50 per cent |
| LABRADORITE | 50 to 30 per cent | 50 to 70 per cent |
| BYTOWNITE | 30 to 10 per cent | 70 to 90 per cent |
| ANORTHITE | 10 to 0 per cent | 90 to 100 per cent |

815



816



Fig. 815, plagioclase with twinning lamellae. Fig. 816, section of a plagioclase with twinning lamellae of Fig. 815, ordinary light. Fig. 816, section in polarized light.

clear angle between the $(110) \wedge (001)$, which is 90° in orthoclase and 24° in albite, and $85^\circ 50'$ in anorthite is 88° in albite, about 90° in oligoclase and andesine, and 91° in anorthite. This transition appears still more strikingly in the position of the "rhombic section," by which the twins according to the pericline law are united as explained below.

Twinning. — The plagioclase feldspars are often twinned in accordance with the Carlsbad, Baveno, and Manebach laws common with orthoclase (p. 536). Twinning is also almost universal according to the albite law — twinning plane the

From albite to anorthite with the progressive change in composition (also specific gravity, melting points, etc.), there is also a corresponding change in crystallographic form, and in certain fundamental optical properties.

Crystalline Form. — The axial ratios and angles given on p. 545 show that these rhetic feldspars approach orthoclase closely in form, the most obvious difference being in the difference angle β between the $(110) \wedge (001)$, which is 90° in orthoclase and 24° in albite. There is also a change in the axial angle γ , which

817



818



819



Fig. 817, rhombic section in albite. Fig. 818, same as anorthite. Fig. 819, 110° and 100° as shown in 110° and 100° extinction-directions in $(001)^\circ$ and $(110)^\circ$.

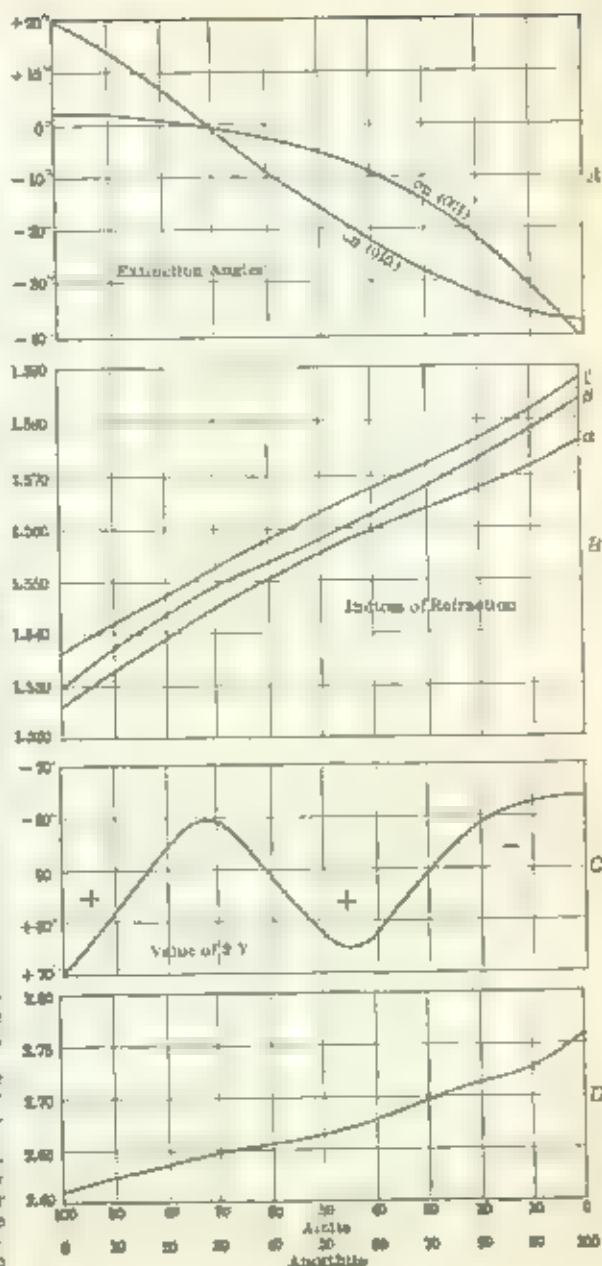
is also almost universal according to the albite law — twinning plane the

brachypinacoid; this is usually polysynthetic, i.e., repeated in the form of thin lamellae, giving rise to fine striations on the basal cleavage surface (Figs. 815, 816). Twinning is also common according to the pericline law - twinning axis the crystal axis b , when polysynthetic this gives another series of fine striations seen on the brachypinacoid.

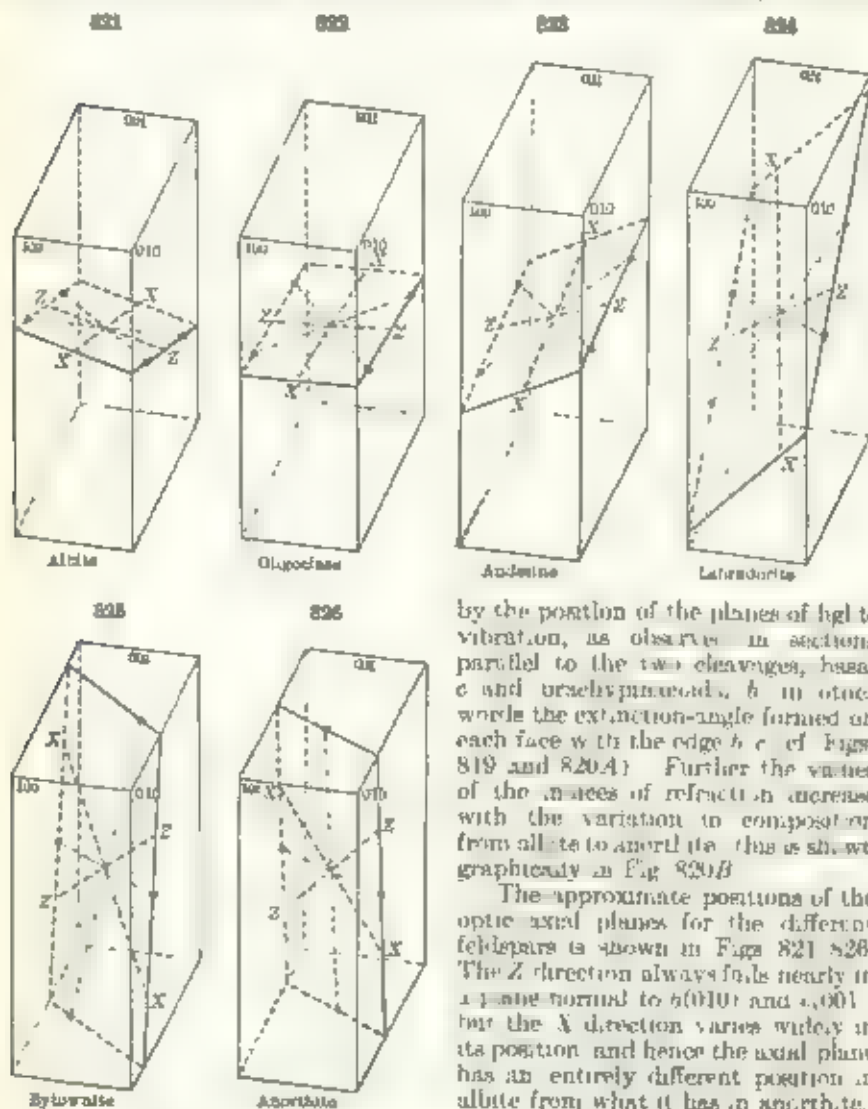
The composition plane in this pericline twinning is a plane passing through the origin in each of the two crystals and is at right angles with the twinning plane and the brachypinacoid. Lamellae of the same composition are parallel to each other. The position of this composition plane and the consequent direction of the striations on the brachypinacoid change rapidly with a small variation in the angle ψ . In general it may be said to be approximately parallel to the base, but in albite it is inclined toward $+$, Fig. 817 and 818 and in anorthite to the front $+$ - Fig. 819. i.e. the intermediate species its position varies progressively with the composition. Thus for the average angle between the trace of this plane on the brachypinacoid and the edge b/c we have for albite $+21^\circ$, for oligoclase $+6^\circ$, for sodicite 0° , for labradorite 6° , for bytownite -12° , for anorthite -18° .

If the composition plane is at right angles or nearly so to the basal plane, as happens in the case of microcline, the polysynthetic lamellae then show prominently in a basal section together with those due to the albite twinning. Hence the grating structure characteristic of microcline.

220



Optical Characters. — There is also a progressive change in the position of the X and Z directions and a consequent change in position of the optic axial plane in passing from albite to anorthite. This is most simply exhibited



by the position of the planes of light-vibration, as observed in sections parallel to the two cleavages, basal c and orthopinacoidal b in other words the extinction-angle formed on each face with the edge b or c of Figs. 819 and 820A). Further the values of the indices of refraction increase with the variation in composition from albite to anorthite (this is shown graphically in Fig. 820B).

The approximate positions of the optic axial planes for the different feldspars is shown in Figs. 821-826. The Z direction always falls nearly in a plane normal to $h(010)$ and $z(001)$, but the X direction varies widely in its position and hence the axial plane has an entirely different position in albite from what it has in anorthite.

The axial angle, $2V$, is always large and its sign varies in different sections of the series, changing from positive with albite to negative in oligoclase-andesine, back again to positive in andesine-labradorite and once more negative in bytownite and anorthite. These variations are shown graphically in Fig. 820C. Another property of

the plagioclase feldspars that varies with the composition to the specific gravity. This is illustrated in Fig. 820D.

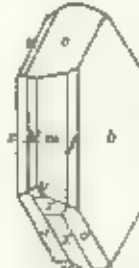
Micro. In rock sections the plagioclase feldspars are distinguished by their lack of color, low refractive power, and low interference-colors, which in polar sections are mainly dark gray, and scarcely rise into white of the first order, also by their maximal character in converging light. In the majority of cases they are easily told by the parallel lamellae or fine lamellae which pass through them, due to the multiple twinning according to the albite law, one set of lamellae or twin lamellae exhibits a general interference-color from the other of Figs. 815, 816. They are thus distinguished not only from quartz and orthoclase, with which they are often associated, but from all the common rock-making minerals. To distinguish the different species and sub-species from one another, as also the form habitative of albite, is more difficult. In sections having a definite orientation (p. 542 and Fig. 816) this can generally be done by determining the extinction angles (p. 542 and Fig. 816). In general in rock sections special methods are required, those are discussed in the various texts devoted to this subject.

ALBITE

Triclinic. Axes $a : b : c = 0.6335 : 1 : 0.5577$; $\alpha = 94^\circ 3'$, $\beta = 116^\circ 20'$, $\gamma = 88^\circ 9'$.

| | |
|----------------------------------------|-----|
| bc , $010 \wedge 001 = 86^\circ 24'$ | 827 |
| mM , $110 \wedge 110 = 59^\circ 14'$ | 828 |
| cm , $010 \wedge 110 = 60^\circ 28'$ | 829 |
| cm , $001 \wedge 110 = 45^\circ 17'$ | |
| cd , $00 \wedge 110 = 69^\circ 10'$ | |
| cc , $001 \wedge 101 = 52^\circ 18'$ | |

Twins as with orthoclase, also very common, the tw. pl. $b(010)$, albite law (p. 542), usually contact-twins, and polysynthetic, consisting of thin lamellae and with consequent fine striations on $c(001)$ (Fig. 830), tw. axis b axis *pericline law*, contact-twins whose composition-



surface is the rhombic section (Figs. 817 and 832), often polysynthetic and showing fine striations which on $b(010)$ are inclined backward $+22^\circ$ to the edge b, c .

Crystals often tabular $b(010)$, also elongated b axis as in the variety *pericline*. Also massive, either lamellar or granular, the laminae often curved, sometimes divergent, granular varieties occasionally quite fine to impalpable.

Cleavage $c(001)$ perfect, $b(010)$ somewhat less so, $m(110)$ imperfect. Fracture uneven to conchoidal. Brittle. $H = 6-6.5$ ($G = 2.40-2.62$). Luster vitreous, on a cleavage surface often pearly. Color white, also occasionally bluish, gray, red, ash greenish, and green, sometimes having a bluish opalescence or play

of colors on $c(001)$. Streak uncolored. Transparent to subtranslucent.

Optically \mp . Extinction-angle with edge $b = +3^\circ$ to 2° on c , and $= +20^\circ$ to 18° on b (Fig. 817). For position of axes plane etc. see Fig. 821. Dispersion for $B_x, \rho < \nu$, also inclined, horizontal $B_x, \rho > \nu$, inclined,



crystal. $\alpha = 1.525$ $\beta = 1.520$ $\gamma = 1.336$ $2V = 70^\circ$ Birefringence weak, $\gamma - \alpha = 0.011$

Comp. A silicate of aluminum and sodium, $\text{NaAlSi}_3\text{O}_8$ or $\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 6\text{SiO}_2$, $\text{SiO}_2 = 59.44$ pct, alumina 19.7, soda 18 = 100. Calcium is commonly present in small amounts, as in orthoclase, $\text{CaAl}_2\text{Si}_2\text{O}_8$, and as the *albite* of the



FIG. 531

FIG. 532

granites through microcline albite to oligoclase (cf. p. 547). Potassium may also be present, and it is then connected with anorthoclase and microcline.

Ver. Cleavage. In crystals and reverse. The crystals

are usually small. The crystals are usually prismatic, with a central cleavage line, and are often found in groups. They are usually colorless, but may be yellowish or grayish. They are usually transparent to translucent. They are usually found in granites, and are often associated with microcline and oligoclase. They are also found in some other rocks, such as the syenites and the nephelinites. They are also found in some metamorphic rocks, such as the gneisses and the schists. They are also found in some igneous rocks, such as the basalts and the andesites.

Per. etc. It is found in the same rocks as the microcline, and is often associated with it. It is also found in some other rocks, such as the syenites and the nephelinites. It is also found in some metamorphic rocks, such as the gneisses and the schists. It is also found in some igneous rocks, such as the basalts and the andesites.

Alb. It is found in the same rocks as the microcline, and is often associated with it. It is also found in some other rocks, such as the syenites and the nephelinites. It is also found in some metamorphic rocks, such as the gneisses and the schists. It is also found in some igneous rocks, such as the basalts and the andesites.

Orth. It is found in the same rocks as the microcline, and is often associated with it. It is also found in some other rocks, such as the syenites and the nephelinites. It is also found in some metamorphic rocks, such as the gneisses and the schists. It is also found in some igneous rocks, such as the basalts and the andesites. It is also found in some other rocks, such as the syenites and the nephelinites. It is also found in some metamorphic rocks, such as the gneisses and the schists. It is also found in some igneous rocks, such as the basalts and the andesites.

It is a very common mineral in the granites, and is often associated with microcline and oligoclase. It is also found in some other rocks, such as the syenites and the nephelinites. It is also found in some metamorphic rocks, such as the gneisses and the schists. It is also found in some igneous rocks, such as the basalts and the andesites. It is also found in some other rocks, such as the syenites and the nephelinites. It is also found in some metamorphic rocks, such as the gneisses and the schists. It is also found in some igneous rocks, such as the basalts and the andesites. It is also found in some other rocks, such as the syenites and the nephelinites. It is also found in some metamorphic rocks, such as the gneisses and the schists. It is also found in some igneous rocks, such as the basalts and the andesites.

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dum and Middletown, Middlesex Co., at Braithville, Fairfield Co. In New York at Marquette and Perryport, St. Lawrence Co. In Virginia, at the mines near Abingdon and at the mines near Abingdon. In Colorado at the Pike's Peak region, Teller Co., with small patches and nodules. From Harberger Hill, Linn. Co., Tenn. In Canada, fine crystals at Wexham, Hastings Co., Ontario. *Triclinic* occurs in Labrador, Lunenburg, etc.

The name *microcline* is derived from *micro*, white, in allusion to its common color.

Use. *SATUR* as optical use. *Microcline* is commonly displayed in some varieties which show an opposition play of colors when polished from a part of the ornamental material known as *microcline*.

THE INTERMEDIATE PLAGIOCLASE FELDSPARS OLIGOCLASE, ANDESINE, LABRADORITE, BYTOWNITE.

Since these do not constitute definite species but represent instead only certain sections of the albitic-anorthite isomorphous series, it seems best to treat them together under one heading.

Triclinic. For crystal constants see table on p. 535. The cleavage angles, Δ (100) \wedge (100) = $90^\circ 42'$, andesine = $96^\circ 14'$, labradorite = $96^\circ 4'$, bytownite = $85^\circ 56'$. Twinning as with albite. Crystals not common. Usually massive, cleavable, granular or compact.

Cleavages as in albite. $H = 5-6$, $G = 2-3$ (2-7); see Fig. 820/1. Color white, gray, greenish, yellowish, brown, reddish, at times colorless. A play of colors is a common character, especially with certain striated rates. Blue and green are the predominant colors, but yellow, brown and pink-gray also occur. This effect has been shown to be at least largely due to the interference of light caused by reflection from thin lamellar inclusions of various minerals. These inclusions lie parallel to (100) or in a plane inclined at 45° to \bar{b} . Varieties with aventuring effects also occur. Transparent to subtransparent. For the optical characters of the series see p. 544 and Figs. 822-825.

Comp. For variations in composition see p. 542. A small percentage of the potash feldspar molecule is very commonly present, also rarely the barium feldspar molecule.

Frag. etc. Fragile in thin splinters. BH with increasing difficulty toward the anorthite end of series. Insoluble or slightly attacked by HCl , the solubility increasing toward the anorthite end.

Obs. *Oligoclase* is a common rock-making mineral, found especially in the more acid igneous rocks, as granite, gneiss, syenite, diorite and the porphyries, and also in some effusive rocks like andesite, trachyte, etc. It is associated with quartz in granite and similar rocks. Notable localities for its occurrence are in Aust. Agder, Norway, at Åmås and Lunde. From various countries in America, e.g., and as the variety *summit* at Tvedestrand, in Sweden, in the neighborhood of Stockholm, at Västby, etc. In the United States in good crystals at Eden, St. Lawrence Co., New York. In Pennsylvania at Mineral Hill, Delaware Co., and at various points in Chester Co. At Baker, Me., Machet Co., New Brunswick, clear glassy crystals, showing cleavage but no twinning. Sources from above and below, common.

Andesine occurs in many granitic and volcanic rocks. It is less common than oligoclase and is especially characteristic of the rocks with medium silica content. It is found in the Andes at Mariposa, California, as an equivalent of the rock called *andesite*, and in various rocks elsewhere. From Roccamare Bay, in the rock known as *tonalite* from the Mte. Adamello district of Trentino, Italy. In France it occurs as *clivage* in a porphyry in the neighborhood of Saint-Etienne in the Esterel, Var. Small crystals come from Mayevana, Japan.

Labradorite is an essential constituent of various igneous rocks, both plutonic and volcanic. It is especially characteristic of the more basic types and usually is associated with some member of the pyroxene or amphibole groups. Thus, it occurs in diorite, gabbro,

amite, epidote, hornblende, etc. At times it is found in amphibolites. Such rocks are most common among the formations of the Archaean era and are to be found in eastern Canada, northern New York, Green and L. Norway, Sweden, Finland, etc. It seldom occurs in distinct crystals. These are, however, found in the schists of Monte Rosa on Fina in Sicily, in the quartz epidiorite of Vesterdal, northeast of Arendalen, Svalbard, Rumania. It is commonly cleavable, usually showing the characteristic play of colors, at various places, the most famous being in eastern Labrador where it occurs in a considerable area in an anorthosite associated with hornblende, hypersthene, and magnetite. Also found in Ontario and Quebec. It occurs abundantly through the central Adirondack region in northern New York.

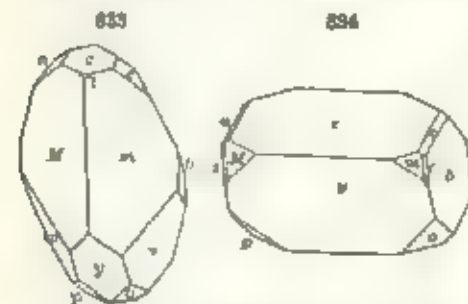
Hylozoite is uncommon, occurring rarely in certain basic plutonic and volcanic rocks. It was originally described from Rytown, northwestern Ontario. This occurrence has been shown to be a mixture of anorthite with quartz, etc.

Use.—The varieties showing a play of colors are used as ornamental material.

MAGNETITE. In various isotropic grains in meteorites, composition near labradorite. Probably represents a re-fused feldspar rather than an original glass.

ANORTHITE. Indiana.

Tricline. Axes $a : b : c = 0.6347 : 1 : 0.5501$, $\alpha = 93^\circ 13'$, $\beta = 115^\circ 55'$, $\gamma = 91^\circ 12'$



| | |
|------|---------------------------------|
| bc | $010 \wedge 001 = 85^\circ 30'$ |
| ab | $110 \wedge 110 = 50^\circ 29'$ |
| bc | $010 \wedge 110 = 58^\circ 4'$ |
| cm | $001 \wedge 110 = 85^\circ 53'$ |
| cm | $001 \wedge 110 = 89^\circ 20'$ |
| cy | $001 \wedge 201 = 81^\circ 14'$ |

Twins as with albite (p. 542 and p. 545). Crystals usually prismatic c axis (Fig. 833, also Fig. 384, p. 164), less often elongated $\parallel b$ axis, like periclase (Fig. 834). Also massive, cleavable, with granular or coarse lamellar structure.

Cleavage: $c(001)$ perfect, $b(010)$ somewhat less so. Fracture conchoidal to uneven. Brittle. $H = 6.5-6.5$ $G = 2.74-2.76$ Color white, grayish, reddish. Streak uncolored. Transparent to translucent.

Optically.—For position of ax. pl. see Fig. 828. Extinction-angles on $c(001)$, 40° with edge b, c , on $b(010)$, 38° (Fig. 819 p. 542). Dispersion $\rho > \nu$. $2V = 77^\circ$. $\alpha = 1.575$. $\beta = 1.583$. $\gamma = 1.588$. Birefringence stronger than with albite.

Comp.—A silicate of aluminum and calcium, $\text{CaAl}_2\text{Si}_2\text{O}_8$ or $\text{CaO Al}_2\text{O}_3 2\text{SiO}_2$. Silica 43.2, alumina 36.7, lime 20.1 = 100. So far as $\text{NaAlSi}_3\text{O}_8$ is usually present in small amount, and as it increases there is a gradual transition through bytownite to labradorite. A small amount of KAlSi_3O_8 usually present.

Var.—Anorthite was described from the glassy crystals of Mts. Norman, Vermont, and *orthoclase* and *basalt* are the same mineral. *Thurstonite* is the same from Ireland. *Indianaite* is a white, grayish, or reddish granular anorthite from Indiana where it occurs in the gangue of carbonaceous iron, described in 1892 by Count Beudantic. It occurs in small, transparent, glassy crystals, tabular $b(010)$ ending cavities in the dolomite of the (Capehart Islands) and near Treva on Fina. *Lepidite*, *labradorite* also belong to anorthite. *Amphibolite* and *pyroxenite* are altered anorthite.

Pyx.—R. B. fuses at 5 to a colorless glass. Artificial anorthite fuses at 1530°C . Anorthite from Mts. Norman, and anorthite from the Carnarvon, India, are decomposed by hydrochloric acid, with separation of gelatinous silica.

Anal. Anartite is the easiest of the feldspars to be formed artificially. In the alkali feldspars it can be easily formed in a dry furnace if it exists in nature. The method becomes progressively more difficult as the alkali molecule is added to the composition. Anartite is frequently observed in waxes and is easily produced in artificial magma. It further is often produced when more complex silicates are broken down by fusion.

Obs. Andulite is rhombohedral, $a = 0.4$ to 0.5 mm, prismatic, with volcanic and plutonic assemblages. It is dark, black, to brown, with a luster like that of graphite. It is found in the same rocks containing chloritoid, garnet, and other minerals. It is common in the same rocks containing chloritoid, garnet, and other minerals. It is common in the same rocks containing chloritoid, garnet, and other minerals.

On the ground, masses of white, opaque, translucent, and brittle, crystalline, anhydrous, *Al-silicate* occurs at Yucca in isolated blocks among the rocks in the range of Mt. Sopron, situated within a granite mass, several miles long. In an *Al-silicate* cavity is found on the *Al-silicate* islands northeast of Yucca, in the *Al-silicate* in Treadwell, N.Y., on the *Al-silicate* of Mt. Mansfield, Vt. In 1888, we traveled to the *Al-silicate* in a case of an *Al-silicate* deposits. In Somerset, N.J., Sweden at Tinsberg and at Åker. In the *Al-silicate* of Tinsberg, in the *Al-silicate* and near the *Al-silicate* of Lunde. In the *Al-silicate* and *Al-silicate*. In the *Al-silicate* of the *Al-silicate* district of Murus, in the *Al-silicate* of the *Al-silicate*. In the *Al-silicate* of the *Al-silicate* of Murus, in the *Al-silicate*, where the *Al-silicate* is covered with a thick crust of lava. In crystals from the *Al-silicate* of New Jersey.

trichloride was applied in 1974 by Rose from *muscula. oblongus*, the crystallization being

Anomosite A feldspar having the composition $\text{Na}_2\text{O} \cdot 2\text{H}_2\text{O} \cdot 3\text{Al}_2\text{O}_3 \cdot 9\text{SiO}_2$. This does not agree with an accessible form of the alkali feldspar series. This is explained by reason of the presence of all the Al of a normal alkali feldspar molecule $\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 6\text{SiO}_2$, to which the other component has been given one or more more nephelites; the average is $\text{Na}_2\text{O} = 45.56$, $\text{SiO}_2 = 26.4$, $\text{Al}_2\text{O}_3 = 55.5$, $\text{H}_2\text{O} = 1.569$, $\text{H}_2\text{SiO}_4 = 1.561$. It is named in honor of Mrs. Anna Maria Anom, wife of John Anom, a Greek name of the mound. *Carnegieite* is named in honor of Andrew Carnegie.

II Metasilicates RSiO_3

Salts of Metasillicic Acid, H_2SiO_3 , characterized by an oxygen ratio of 2 : 1 for silica to bases. The Division closes with a number of species, in part of somewhat doubtful composition, forming a transition to the orthosilicates.

The metagabbros include two prominent and well-characterized groups, viz. the Pyroxene Group and the Amphibole Group. There are also others less important.

Leucite Group. Isometric

In several respects *leucotis* is allied to the species of the *FELICIA* GROUP, which immediately precede.

| | | |
|-----------|------------------------------------------------------------|-------------------|
| Leucite | $\text{KAl}(\text{Si}_3\text{O}_9)^+$ | Isometric at 500° |
| | Pseudo-isometric at ordinary temperatures | |
| Pollucite | $\text{H}_2\text{U}_2\text{As}_2(\text{Si}_3\text{O}_9)_2$ | Isometric |

LEUCITE Amphibole.

Isometric at about 400° C., pseudo-isometric under ordinary conditions (see p. 34). Commonly in crystals varying in angle but little from the trapezohedron $\pi(211)$, sometimes with $\alpha(100)$ and $\beta(110)$ as subordinate forms. Faces often showing fine striations due to twinning (Fig. 835). Also in disintegrated grains: rare & massive granular.

5:5-6. G = 2.45-2.50. Luster vitreous. Color white, ash-gray or smoke-gray. Streak uncolored. Translucent to opaque. Usually shows very

in the Loupette Hills in the Green River Basin, Wyoming; in the Absaroka Range in the Yellowstone Park, Wyoming; at the Highwood and Bearpaw Mts. Montana; in part pseudomorphs. On the shores of Vancouver Island, British Columbia, where magnificent groups of crystals have been found as large as feet.

Named from *véridé, vérite*, a reference to its color.

Polycryst. Essentially $\text{H}_2\text{SiO}_3 \cdot \text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$, isometric, often in cubes, also massive. H. = 6.5 G. = 2.601 (colorless). $n = 1.525$ (occurs very sparingly in the island of Ellis, with petalite (celestine) also at Hebron and Randolph, Maine.

Ussingite. — $\text{HNa}_2\text{Al}_2(\text{SiO}_3)_2$. Triclinic. Three cleavages. $\alpha = 2.6$ H. = 6-7. Color reddish violet. In trace, 1.50-1.55. Easily fusible. Soluble in hydrofluoric acid. Found in round masses from pegmatite at Hungerford, Massachusetts, also from Isla Pampala, Ruman Lophium.

Pyroxene Group

Orthorhombic, Monoclinic, Triclinic

Composition for the most part that of a metasilicate, RSiO_3 , with $\text{R} = \text{Ca, Mg, Fe}$ chiefly, also Mn, Zn . Further RSiO_3 with $\text{R} = \text{Fe, Al, Si}$, less often containing alkalis (Na, K), and then RSiO_3 with $\text{RAl(SiO}_3)_2$. Rarely including arsenium and titanium, also fluorine.

Orthorhombic Section

| | | a | b | c |
|--------------------|-------------------------------|--------|-----|--------|
| Kestattite | MgSiO_3 | 1.0308 | 1.0 | 0.5885 |
| Bronzite | $(\text{Mg, Fe})\text{SiO}_3$ | | | |
| Hypersthene | $(\text{Fe, Mg})\text{SiO}_3$ | 1.0319 | 1.0 | 0.5865 |

The positions of the a and b axes are reversed from the usual orthorhombic orientation in order to emphasize the similarity of form between the orthorhombic and monoclinic pyroxenes.

Monoclinic Section

| | | $a : b : c$ | β |
|--------------------------|---------------------------------------------------------------|-------------|-----------------|
| Pyroxene | | 1.0921 | 1.05893 74° 10' |
| 1. CLINOENSTATITE | MgSiO_3 | | |
| 2. PLEIOENITE | Intermediate between clinoenstatite and diopside | | |
| 3. DIOPSIDE | $\text{CaMg}(\text{SiO}_3)_2$ | | |
| 4. HEDENBERGITE | $\text{CaFe}(\text{SiO}_3)_2$ | | |
| 5. AUGITE | CaMgSiO_3 with $\text{Mg, Fe, Al, Fe}_2\text{SiO}_4$ | | |

| | | a | b | c | β |
|-------------------------|-------------------------------|--------|-----|--------|---------|
| Acmite (Eggsite) | NaFeSiO_3 | 1.0996 | 1.0 | 0.6012 | 73° 11' |
| Jadeite | NaAlSiO_3 | 1.105 | 1.0 | 0.613 | 72° 44' |
| Spodumene | $\text{LiAl}(\text{SiO}_3)_2$ | 1.1238 | 1.0 | 0.6155 | 69° 40' |

Triclinic Section

| | | a | b | c | α | β | γ |
|---------------------|-----------------------------------------------------------------|--------|-----|--------|-----------|----------|----------|
| Rhodonite | MnSiO_3 | 1.0729 | 1.0 | 0.6213 | 103° 18' | 108° 44' | 81° 39' |
| Babingtonite | $(\text{Ca, Fe, Mn})\text{SiO}_3 \cdot \text{Fe}_2\text{SiO}_4$ | 1.0691 | 1.0 | 0.6308 | 104° 21½' | 108° 31' | 83° 34' |

The PYROXYNE GROUP embraces a number of species which, while falling in different systems — orthorhombic, monoclinic, and triclinic — are yet

closely related in form. Thus all have a fundamental prism with an angle of 93° and 87° , parallel to which there is more or less distinct cleavage. Further, the angles in other prominent zones show a considerable degree of similarity. In composition the metasilicates of calcium, magnesium, and ferrous iron are most prominent, while compounds of the form $R(Al,Fe)_2SiO_6$, RAI_2SiO_6 are also important.

The atomic structure of the monoclinic pyroxenes, as shown by X-ray analysis, has the following characteristics. Each silicate atom lies in the center of a tetrahedron with four oxygen atoms at its points. These tetrahedral groups are linked together into chains by the sharing of one oxygen atom between two adjacent groups; i. e., in each group two oxygen atoms also belong half to the groups on either side. This makes the silicon-oxygen ratio equal SiO_4 . These chains of silicon-oxygen tetrahedra are parallel to the vertical crystal axis and are bound together laterally by the calcium and magnesium atoms. The magnesium atoms lie within a group of six oxygen atoms while the calcium atoms are within a somewhat irregular group of eight oxygen atoms. The prismatic cleavage of pyroxene takes place between the silicon-oxygen chains.

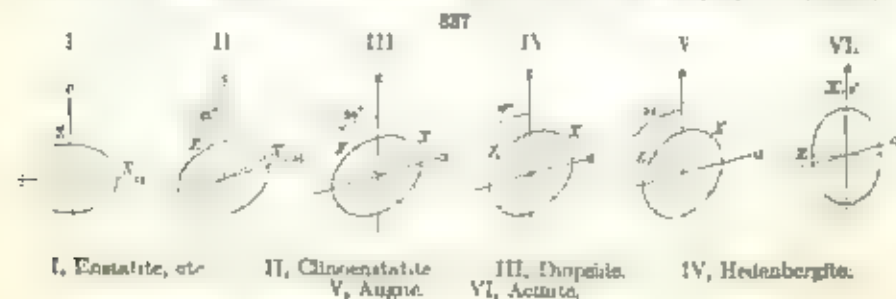
The structure of the orthorhombic pyroxene, enstatite, is similar to that of the monoclinic pyroxene. The unit cell of enstatite corresponds very closely to two unit cells of pyroxene divided by their (100) faces, one the reflection of the other. The unit cell gives an axial ratio in which the value of a or b in the orientation usually used is twice that usually given. Each cell contains sixteen molecules.

The species of the pyroxene group are closely related in composition to the corresponding species of the amphibole group, which also embraces members in the orthorhombic, monoclinic, and triclinic systems. In a number of cases the same chemical compound appears in each group, furthermore a change by polymorphism of pyroxene to amphibole is often observed. In form also the two groups are related as shown in the axial ratio, also in the parallel growth of crystals of monoclinic amphibole upon or about axes of pyroxene (Fig. 147, p. 196). The axial ratios for the typical monoclinic species are:

| | | |
|-----------|-----------------------------------|------------------------|
| Pyroxene | $a : b : c = 1.0921 : 1 : 0.5893$ | $\beta = 71^\circ 10'$ |
| Amphibole | $a : b : c = 1.1022 : 1 : 0.5875$ | $\beta = 73^\circ 58'$ |

See further on p. 569.

The general relations of the prominent members of the Pyroxene Group, especially as regard to the connection between the position of the crystal axes and the crystal graphic axes are exemplified in the following figures (Cross)



A corresponding exhibition of the prominent amphiboles is given under that group, Fig. 384, p. 570.

Orthorhombic Section

The orthorhombic pyroxenes enstatite and hypersthene form a continuous isomorphous series for which the name *ensthene* has been proposed. Commonly by enstatite (a designation of the $MgSi_2O_6$ end of the series meaning that it is up to those containing 15 per cent of Fe). These are optically positive. The remainder of the series is optically negative and is known as hypersthene.

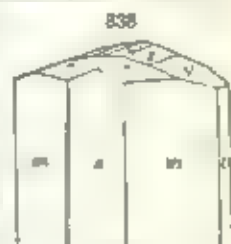
ENSTATITE

Orthorhombic. Axes $a : b : c = 0.9702 : 1 : 0.5710$, see also p. 351)

| | |
|---------------------------------------------------------|--------------------------------------------------------|
| $\mu_{100} = 110^\circ \wedge 110^\circ = 89^\circ 56'$ | $\mu_{110} = 71^\circ \wedge 110^\circ = 40^\circ 16'$ |
| $\mu_{010} = 023^\circ \wedge 023^\circ = 41^\circ 41'$ | $\mu_{011} = 25^\circ \wedge 011^\circ = 49^\circ 14'$ |

Twins rare. (tw pl $h(014)$) as twinning lamellae. (tw pl $h(101)$) as striae. Twins crossing at angles of nearly 90° sometimes observed. Distinct crystals rare, habit prismatic. Locally massive. Fibrous or lamellar. See p. 552 for discussion of atomic structure and relation to monoclinic pyroxene.

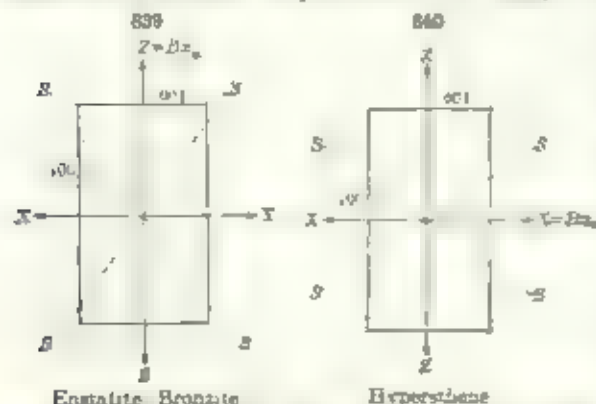
Cleavage $m(110)$ rather easy. Parting $h(010)$ also $a(100)$. Fracture uneven. Brachy $H = 4.5$. $G = 3.1-3.3$. Luster vitreous to nearly in cleavage-surfaces to vitreous. Often dull and in the fibrous variety. Color grayish yellow or greenish white to olive-green and brown. Streak unaltered, grayish. Translucent to nearly opaque. Pleochroism weak more marked in varieties relatively rich in iron. Optically +. Ax pl $\delta(011)$. Bx $\epsilon \perp c(001)$. (cf Fig. 549). Dispersion $\rho < \gamma$ weak. Ax. angle large and variable increasing with the amount of iron usually about 90° for FeO = 10 per cent. $\alpha = 1.650$, $\beta = 1.655$, $\gamma = 1.658$ for $MgSi_2O_6$.



Enstatite

$\beta = 1.6658$, $\gamma = 1.6716$ (containing about 5 per cent FeO).

Comp. — $MgSi_2O_6$ or $Mg_2Si_2O_6 = 84.6$ magnesia 10 = 100. Practically always contains iron giving the general formula, $(Mg, Fe)_2Si_2O_6$. The percentage of FeO present may vary up to about 15.



lowish, grayish or greenish white. pure vitreous to nearly opaque. In the fibrous variety the color is more variable. In the massive variety it is more uniform. In the fibrous variety it is more variable. In the massive variety it is more uniform. In the fibrous variety it is more variable. In the massive variety it is more uniform.

on a cleavage-surface, and sometimes metalloidal. Color dark brownish green, grayish black, greenish black, puceblack-brown. Streak grayish, brownish gray. Translucent to nearly opaque. Pleochroism after staining, especially in the kinds with high iron percentage: thus, X or a axis brownish red, Y or b axis red-ash yellow, Z or c axis green. Optically: $Ax \parallel b$, $b = 1.0$, $Bx_{\infty} \perp a$ (100). Dispersion $\rho > \nu$. Axial angle rather large and variable, diminishing with increase of iron, cf. estimate, $p = 53$, and $P_{\infty} = 819$, 840 , $p = 553$. Indices for variety with about 15 per cent FeO, $\alpha = 1.652$, $\beta = 1.702$, $\gamma = 1.705$.

Hypersphere often encloses minute tabular scales, usually of a brown color, arranged in rows parallel to the base plane. Fig. 411 also seen from a vertical direction, b or c axis, thus they may be visible growth of hornblende. These crystals are often of secondary origin, the nucleus of the peridiar mineral being a hornblende, and are often of secondary origin, being developed along the so-called 'reaction planes' (p. 211).

Comp. — $(Fe, Mg)(Si)_2$ with FeO greater than 15 per cent. Aluminum is sometimes present (up to 10 per cent, and the estimation then approximate) in the aluminous pyroxenes.

Pyx. etc. R.R. fuses to a black enamel, and on charcoal yields a magnetic mass, fuses more easily with increasing amount of iron. Partially decomposed by fusion with NaOH.

Micro. — In thin sections similar to enstatite except shows distinct redness or greenish color with stronger pleochroism and is optically different.

Anal. — See table to which see.

Obs. — Hornblende associated with a tridinic feldspar, abundant, as a common certain granitic gneiss in the north of the hornblende gneiss, and more common in the hornblende rocks, trachyte and quartzite, and in the hornblende rocks, where it was abundant. The hornblende is associated with the hornblende rocks, where it was abundant. The hornblende is associated with the hornblende rocks, where it was abundant.

Hypersphere occurs in large crystals in the hornblende at Badensheim, Bavaria, in various places in Norway and Greenland. In large crystals in the hornblende at Badensheim, Bavaria, in various places in Norway and Greenland. In large crystals in the hornblende at Badensheim, Bavaria, in various places in Norway and Greenland. In large crystals in the hornblende at Badensheim, Bavaria, in various places in Norway and Greenland.

In the United States it occurs in New York in the north of the hornblende region, in the Hudson River and in the Adirondack region. In the north of the hornblende region, in the Hudson River and in the Adirondack region. In the north of the hornblende region, in the Hudson River and in the Adirondack region.

The hornblende is found in various places, in the north of the hornblende region, in the Hudson River and in the Adirondack region.

Hypersphere is found in various places, in the north of the hornblende region, in the Hudson River and in the Adirondack region. In the north of the hornblende region, in the Hudson River and in the Adirondack region. In the north of the hornblende region, in the Hudson River and in the Adirondack region.

In the United States, 2 Mg FeSi₂ (Mg, Fe Si₂). Occurs in rounded nodules in the metamorphosed hornblende, in the north of the hornblende region, in the Hudson River and in the Adirondack region.

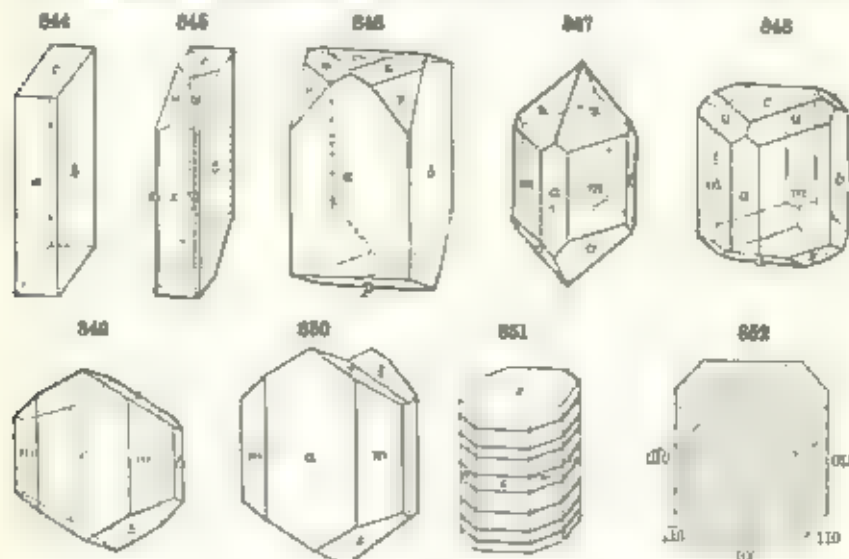
Monoclinic Section

PYROXENE.

Monoclinic Axes $a = b = c = 1.0921$ $1 = 0.5803$ $\beta = 74^\circ 10'$

| | | | |
|----|-----------------------------|----|----------------------------|
| mm | 110 \wedge 110 = 92° 50' | cr | 001 \wedge 221 = 40° 1' |
| cr | 001 \wedge 100 = 74° 10' | cr | 001 \wedge 110 = 40° 1' |
| cr | 001 \wedge 101 = 31° 30' | cr | 001 \wedge 111 = 40° 1' |
| cr | 011 \wedge 011 = 90° 0' | cr | 111 \wedge 111 = 31° 30' |
| cr | 021 \wedge 021 = 97° 11' | cr | 111 \wedge 111 = 31° 30' |
| cr | 001 \wedge 111 = 33° 494' | cr | 221 \wedge 221 = 84° 31' |

Twins tw pl (1) $a(100)$ contact-twins, common (Fig 850) sometimes polysynthetic (2 $c(001)$ as twinning lamellae producing striations on the vertical faces and pseudocleavage or parting $c(001)$ Fig 851), very common, often secondary (3 $y(101)$ cruciform-twins, not common (Fig 477, p. 193) (4 W 122) the vertical axes crossing at angles of nearly 60° , sometimes repeated as a six-rayed star Fig 476, p. 193) Crystals usually prismatic in habit, often short and thick, and either a square prism ($a(100)$, $b(010)$, prominent or nearly square 93° , 87°) with $m(110)$ predominating; some-

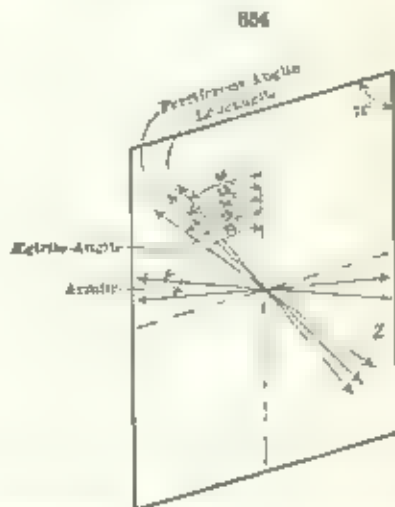


times a nearly symmetrical 6-sided prism with a , b , m (Fig 851). Often coarsely lamellar $a(101)$, or $a(100)$. Also granular, coarse or fine rarely fibrous or columnar.

Cleavage $m(110)$ sometimes rather perfect, but interrupted, often only observed in thin sections c axis (Fig 852). Parting $c(001)$, due to twinning, often prominent especially in large crystals and large masses (Fig 851) also $a(100)$ less distinct and not so common. Fracture uneven to conchoidal. Brittle $H = 5.6$ $G = 3.2-3.5$ varying with the composition. Luster various inclining to resinous often dull, sometimes nearly $c(001)$ in kind showing parting. Color usually green, various shades, varying from nearly colorless, white, or grayish white to brown and black rarely bright green, some kinds containing chromium, also blue. Streak white to gray and grayish green. Transparent to opaque. Pleochroism usually weak even in dark-colored varieties. Sometimes marked, especially in the brown kinds containing titanium. (Idolite is name given to a highly pleochroic variety from the Caucasus Mts.)

Optically \pm . Birefringence strong, $\gamma - \alpha = 0.02 - 0.03$. Ax pl usually $b(010)$ Bx or Z c axis $\approx 36^\circ$ in diaspore, to $\approx 52^\circ$ in augite (which see) or $Z \wedge c(001) = 20^\circ$ to 30° , the angle in general increasing with amount of iron. For diaspore $2V = 59^\circ$ $\alpha = 1.664$, $\beta = 1.6715$, $\gamma = 1.694$

Comp. — For the most part a normal metasilicate, RSiO_3 , chiefly of calcium and magnesium also iron, less often manganese and zinc. The alkali metals potassium and sodium present rarely except in very small amount. Also in certain varieties containing the trivalent metals aluminum, ferric iron, and manganese. These last varieties may be most simply considered as molecular compounds of (a) Mg, Fe, MnO_3 and (b) $\text{Mg, Fe, Al, Fe, SiO}_3$, as suggested by Tschermak. Chromium is sometimes present in small amount, also titanium replacing silicon.



The name *pyroxene* is from *pyr*, fire and *oxen*, stronger and records Haüy's idea that the mineral was, as he expressed it, "a stranger to the domain of fire." *Pyroxene*, in fact, is, next to the feldspar, the most universal constituent of igneous rocks.

The varieties are numerous and depend upon variations in composition chiefly, the more prominent of the varieties properly rank as sub-species.

1 CLINOENSTATITE MgSiO_3 . Study of artificial crystals show that they are rhombohedral and either tabular after 100 or prismatic after 1100 and always elongated parallel to the *c* axis. Polysynthetic twinning on a {100} very characteristic. Good prismatic cleavage at 85°. Colorless to yellow. $\text{Ax. pl.} \perp b \text{ axis}$. $Z \wedge c \text{ axis} = 22^\circ$ see Fig. 537. $a = 1.651$, $b = 1.661$, $\gamma = 1.660$. $2V = 53^\circ 30'$. Composition varies with iron replacing magnesium and grades into what has been called *clinohypersthene*. An increasing percent age of iron is accompanied with a rise in value of indices and of the extinction angle, $Z \wedge a, c \text{ axis}$.

MgSiO_3 can be crystallized from a melt having the theoretical composition at about 1500° C. or at a lower temperature from solution in water containing or magnesium silicate. It is the most refractory of MgSiO_3 . It has no true melting point but at 1507° C. breaks down into kinkrite and silica.

Clinoenstatite occurs rarely in igneous rocks and meteorites. Clinohypersthene is known only in meteorites.

2. PIGEONITE. Intermediate between clinoclasite and diopside, a mixture of the molecules $MgFeSiO_3$ and $CaMgSiO_3$. A similar compound may occur in the series between clinoclasite and hedenbergite. General physical properties like those of diopside. $AX \text{ in } 1000$ in varieties low in lime ranging to 010 at a content of 7 or 10 per cent CaO . AX angle small and variable. Optically $\pm Z \wedge c$ axis varies from 22° to 45° increasing with lime content. Occurs at various points in diabase, gabbro, gneiss, etc. Named from occurrence at Pigeon Point, Massachusetts.

3. DIOPSID. Melionite, Analcite. *Calcium-magnesium pyroxene*. Formula $CaMgSiO_3$, $\text{lime } 55.6$, $\text{lime } 25.9$, $\text{magnesia } 18.5 = 100$. Color white, yellowish, grayish white to pale green, and finally to dark green and nearly black, sometimes transparent and colorless, also rarely a fine blue. In prismatic crystals often slender, also granular and cellular in massive masses. $G = 3.2-3.35$. $Z \wedge c$ axis = $+36^\circ$ to 40° . For indices see above. Iron is present usually in small amount as noted below, and the amount increases as it graduates toward true hedenbergite.

The following being here. *Chromodiopside*, contains chromium 1 to 2½ per cent Cr_2O_3 , often a fine red tinge.

Maugelite, as originally described, was a pale-colored translucent variety from Svala, Sweden.

Analcite occurs in typical right-angled prisms, colorless to faint greenish or clear green, from the Mjøsa type in the Ålviken, Piedmont, Italy.

Triclinic from Traversella, Piedmont, Italy, is similar.

Diopside is a fine blue diopside from St. Marcel, Piedmont, Italy, occurring in prismatic crystals and massive.

Clausthalite is a grayish white or bluish white pyroxene occurring with clausenite at Clausthal, Clausthal.

Lauvåne is a pyroxene, colored green by vanadium, from the neighborhood of Lake Hauke, a variety of Svala.

Maugelite is a chrome-bearing pyroxene composed largely of the diopside and hedenbergite molecules, occurring in contact metamorphic limestone from Maugé Mountain, parish of Looe, Highland, northern Sweden.

Diopside is named from its color in double, and often, appearance. *Maugelite* is from *maugé*, soft, because softer than *maugé* with which it was associated.

4. HEDENBERGITE. *Calcium-iron pyroxene*. Formula $CaFeSiO_3$, $\text{Silica } 48.4$, $\text{iron protoxide } 29.4$, $\text{lime } 22.2 = 100$. Color black. In crystals, and also lamellar massive. $G = 3.5-3.58$. $Z \wedge c$ axis = $+40^\circ$ to 48° . $\alpha = 1.739$, $\beta = 1.745$, $\gamma = 1.757$. Manganese is present in *manquhedenbergite* to 6.5 per cent. Color grayish green. $G = 3.55$.

Between the two extremes diopside and hedenbergite there are numerous transitions ending up to the formula $CaMgFeSiO_3$. As the amount of iron increases the color changes from light to dark green to nearly black, the specific gravity increases from 3.4 to 3.6, and the angle $Z \wedge c$ axis also from 26° to 48° .

The following are varieties coming under these two subspecies, based in part upon structure, in part on peculiarities of composition.

Sulfer. Said to come grayish green to deep green and black, sometimes grayish and yellowish white in crystals, also has a granular (001) and granular massive form from Svala. Black to a dark, mossy green variety, in crystals, with prismatic (001), from Lake Hauke in Svala.

Clausthalite is a granular variety, embedded in calcite, also forming loosely coherent to compact aggregations, color varying from white to pale green to dark green, and then containing considerable iron, the latter the original color. Named from Clausthal, a variety.

Diopside. A lamellar or fibrous pyroxene, characterized by a fine lamellar structure in parting a (100) with some prismatic (010) in some other (001). Also a fibrous structure. Twinning a (100) often polysynthetic interpenetration with an orthorhombic pyroxene common. Color grayish green to bright green-green and deep

green also brown. Luster of surface a little glassy, sometimes metallic or exhibiting iridescence and reflecting brownish green from the presence of minute, or in amount of secondary origin. $\text{Stk. A c axis} = +39 \text{ to } 40^\circ$, $\mu = 1.661$, $\gamma = 2$, $\alpha = 1.643$, $\text{H} = 4$, $G = 32-35$. In composition near diopside, but often containing also the and sometimes in rounded or irregular form proper to be classed as a glass. Often changed to amphibole or actinolite and calcite, p. 574. *Notes:* - In the same diagenetic and metamorphic conditions as the diagenetic and metamorphic rocks. This is the characteristic pyroxene of gabbro, and other related rocks.

Amphibolite. The granular to foliated pyroxene constituent of the garnet-rock called oringite, often interlaminated with amphibole. emeraldine color gray-green. Contains some Al_2O_3 .

SCHAEFFERITE. A manganese pyroxene, sometimes also containing much iron. Color brown to black.

In crystals, sometimes tabular - 010 also with $p\{101\}$ prominent, more often elongated in the direction of the zone $\{010\}$ $p\{101\}$ rarely prominent. Axes: Tangent with $a\{100\}$ as the 1^{st} axis common. Also containing massive cleavage probably very distinct. Color yellowish brown to reddish brown, on black very effective. Crystallographically $Z = c$ axis = 44.2° . The most effective from large ones. Number is black in color and has $Z \angle c$ axis = 44.2° to 50° for different sizes. Many crystals. The brown group is heliophane, abundant from Langbanstuvan, Sweden, has $Z \angle c$ axis = 45.3° . It resembles garnet in appearance.

Isfernaulite is a manganese-iron pyroxene from Franklin Furnace, New Jersey. But the zinc may be 10 to 20 per cent. In large coarse crystals with eigh rounded and faces uneven. Color greenish-brown on the exposed surface, becomes brown.

Planorbis. A few were containing some molluscs, mangrove and not strongly pleurostomate. Found with mangrove in the central provinces, India.

5. **ARGONITE.** *Aluminous pyroxene.* Composition chiefly $\text{CaMgSi}_2\text{O}_6$ with $(\text{Mg, Fe, Al, Fe}_2\text{SiO}_4)$ and occasionally also containing alkalis and then graduating toward arfvedsonite. Titanium is also sometimes present. There are various explanations of the composition of the pyroxenes containing the sesquioxides, their exact character must still be considered as unsettled. Here belong:

Color white or grayish. Contains alumina, with lime and magnesia, and little or no iron. Lays like diopside. ZAc axis = + 40° to 45° $H = 6.5$, $G = 3.10$

b. **Passerine** Includes the jays to dark, sometimes deep-green cardinals, or rustar-birds, green and then becoming sparrow. The mountainous birds of the Alps, some including here. Includes from the mountainous birds of the Alps, some including here.

1. *Testes* - indicates the greenish or brownish blue and blue & blue occurring mostly in arctic or rocky. It is usually a short process, ovate, 0.6-1.0 mm. x or tubular 1-1.5 mm. often with 4-5 1-50 μ long which are present in a relatively large amount at the angle Z - also ranges from +45 to 50°. Indicate variable $\tau = 1/100 \pm 1$. When rich in iron or thin as indicated satisfactorily provides: X = greenish yellow or reddish; F = brownish red or violet; Z = greenish yellow, reddish, or violet. Sourced from *Smithsonian*.

of diagenite-silicate. Here being varieties of silicate characterized by the presence of aluminates, especially scapolite, commonly in the form of the anorthite molecule, NaAlSi₃O₈. % Al₂O₃ = 54 to 55, % SiO₂ = 42 to 43. In the percentage of the acid is present as it is, there is an increase in the acid from 23% and in the silicate from 31% to 41% and 54% by plagioclase, and 5 and 6 being the ratio of green. 2 being the ratio of brown, chiefly from rocks rich in aluminates, as nepheline-silicate, plagioclase, etc.

Pyt. etc. Varying α and β are the wide differences in composition in the different varieties and after 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99, 100, 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111, 112, 113, 114, 115, 116, 117, 118, 119, 120, 121, 122, 123, 124, 125, 126, 127, 128, 129, 130, 131, 132, 133, 134, 135, 136, 137, 138, 139, 140, 141, 142, 143, 144, 145, 146, 147, 148, 149, 150, 151, 152, 153, 154, 155, 156, 157, 158, 159, 160, 161, 162, 163, 164, 165, 166, 167, 168, 169, 170, 171, 172, 173, 174, 175, 176, 177, 178, 179, 180, 181, 182, 183, 184, 185, 186, 187, 188, 189, 190, 191, 192, 193, 194, 195, 196, 197, 198, 199, 200, 201, 202, 203, 204, 205, 206, 207, 208, 209, 210, 211, 212, 213, 214, 215, 216, 217, 218, 219, 220, 221, 222, 223, 224, 225, 226, 227, 228, 229, 230, 231, 232, 233, 234, 235, 236, 237, 238, 239, 240, 241, 242, 243, 244, 245, 246, 247, 248, 249, 250, 251, 252, 253, 254, 255, 256, 257, 258, 259, 260, 261, 262, 263, 264, 265, 266, 267, 268, 269, 270, 271, 272, 273, 274, 275, 276, 277, 278, 279, 280, 281, 282, 283, 284, 285, 286, 287, 288, 289, 290, 291, 292, 293, 294, 295, 296, 297, 298, 299, 300, 301, 302, 303, 304, 305, 306, 307, 308, 309, 310, 311, 312, 313, 314, 315, 316, 317, 318, 319, 320, 321, 322, 323, 324, 325, 326, 327, 328, 329, 330, 331, 332, 333, 334, 335, 336, 337, 338, 339, 340, 341, 342, 343, 344, 345, 346, 347, 348, 349, 350, 351, 352, 353, 354, 355, 356, 357, 358, 359, 360, 361, 362, 363, 364, 365, 366, 367, 368, 369, 370, 371, 372, 373, 374, 375, 376, 377, 378, 379, 380, 381, 382, 383, 384, 385, 386, 387, 388, 389, 390, 391, 392, 393, 394, 395, 396, 397, 398, 399, 400, 401, 402, 403, 404, 405, 406, 407, 408, 409, 410, 411, 412, 413, 414, 415, 416, 417, 418, 419, 420, 421, 422, 423, 424, 425, 426, 427, 428, 429, 430, 431, 432, 433, 434, 435, 436, 437, 438, 439, 440, 441, 442, 443, 444, 445, 446, 447, 448, 449, 450, 451, 452, 453, 454, 455, 456, 457, 458, 459, 460, 461, 462, 463, 464, 465, 466, 467, 468, 469, 470, 471, 472, 473, 474, 475, 476, 477, 478, 479, 480, 481, 482, 483, 484, 485, 486, 487, 488, 489, 490, 491, 492, 493, 494, 495, 496, 497, 498, 499, 500, 501, 502, 503, 504, 505, 506, 507, 508, 509, 510, 511, 512, 513, 514, 515, 516, 517, 518, 519, 520, 521, 522, 523, 524, 525, 526, 527, 528, 529, 530, 531, 532, 533, 534, 535, 536, 537, 538, 539, 540, 541, 542, 543, 544, 545, 546, 547, 548, 549, 550, 551, 552, 553, 554, 555, 556, 557, 558, 559, 560, 561, 562, 563, 564, 565, 566, 567, 568, 569, 570, 571, 572, 573, 574, 575, 576, 577, 578, 579, 580, 581, 582, 583, 584, 585, 586, 587, 588, 589, 590, 591, 592, 593, 594, 595, 596, 597, 598, 599, 600, 601, 602, 603, 604, 605, 606, 607, 608, 609, 610, 611, 612, 613, 614, 615, 616, 617, 618, 619, 620, 621, 622, 623, 624, 625, 626, 627, 628, 629, 630, 631, 632, 633, 634, 635, 636, 637, 638, 639, 640, 641, 642, 643, 644, 645, 646, 647, 648, 649, 650, 651, 652, 653, 654, 655, 656, 657, 658, 659, 660, 661, 662, 663, 664, 665, 666, 667, 668, 669, 670, 671, 672, 673, 674, 675, 676, 677, 678, 679, 680, 681, 682, 683, 684, 685, 686, 687, 688, 689, 690, 691, 692, 693, 694, 695, 696, 697, 698, 699, 700, 701, 702, 703, 704, 705, 706, 707, 708, 709, 710, 711, 712, 713, 714, 715, 716, 717, 718, 719, 720, 721, 722, 723, 724, 725, 726, 727, 728, 729, 730, 731, 732, 733, 734, 735, 736, 737, 738, 739, 740, 741, 742, 743, 744, 745, 746, 747, 748, 749, 750, 751, 752, 753, 754, 755, 756, 757, 758, 759, 760, 761, 762, 763, 764, 765, 766, 767, 768, 769, 770, 771, 772, 773, 774, 775, 776, 777, 778, 779, 780, 781, 782, 783, 784, 785, 786, 787, 788, 789, 790, 791, 792, 793, 794, 795, 796, 797, 798, 799, 800, 801, 802, 803, 804, 805, 806, 807, 808, 809, 810, 811, 812, 813, 814, 815, 816, 817, 818, 819, 820, 821, 822, 823, 824, 825, 826, 827, 828, 829, 830, 831, 832, 833, 8

Diff. (characterised by maximum crystallisation at the periphery of the spherulite) and 93°, hence yielding nearly square plates, these may be mistaken for spherulite if terminal

Crystals of garnet often show a marked zonal structure, green within and brown on the outside. The green is due to the presence of Fe^{2+} and the brown to the presence of Fe^{3+} . The garnet is often found in the same rock as the quartz and the mica. The garnet is often found in the same rock as the quartz and the mica. The garnet is often found in the same rock as the quartz and the mica.

Comp Essentially $\text{NaFeSi}_3\text{O}_8$, or Na_2O 48.6, SiO_2 51.4 = 100. (Note: 52.0 atom sesquioxide 34.6, soda 13.4 = 100.)

The garnet is often found in the same rock as the quartz and the mica. The garnet is often found in the same rock as the quartz and the mica. The garnet is often found in the same rock as the quartz and the mica.

For etc. The garnet is often found in the same rock as the quartz and the mica. The garnet is often found in the same rock as the quartz and the mica.

Micro The garnet is characterised by its zonal structure, green within and brown on the outside. The garnet is often found in the same rock as the quartz and the mica.

Anal The garnet is often found in the same rock as the quartz and the mica. The garnet is often found in the same rock as the quartz and the mica.

Obs The garnet is often found in the same rock as the quartz and the mica. The garnet is often found in the same rock as the quartz and the mica.

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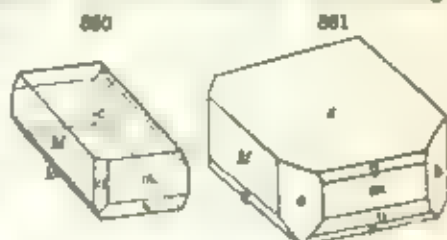
JADEITE.

Monoclinic. Axes $a : b : c = 1.031 : 0.613 : 0.724$. Usually massive, but may be striated, sometimes granular also. Occurs in the same rock as the quartz and the mica.

The garnet is often found in the same rock as the quartz and the mica. The garnet is often found in the same rock as the quartz and the mica. The garnet is often found in the same rock as the quartz and the mica.

Comp Essentially $\text{NaAlSi}_3\text{O}_6$, or Na_2O 48.6, SiO_2 51.4 = 100. (Note: 52.0 atom sesquioxide 34.6, soda 13.4 = 100.) It is a pyroxene with the same composition as the jadeite, but that it is jade and that they may form more or less continuous series with each other.

Cleavage: $m(110)$, $M(1\bar{1}0)$ perfect $c(001)$ less perfect. *Bustamite* shows perfect cleavage $\{010\}$. Fracture conchoidal to uneven. Very tough when compact. $H = 5.5-6.5$ $G = 3.4-3.68$. Luster vitreous, on cleavage surfaces somewhat pearly. Color light brownish red, flesh-red, rose-pink, sometimes greenish or yellowish, when impure, often black outside from exposure. Streak white. Transparent to translucent. Optically + or - $2V = 70^\circ$ $\alpha = 1.72-1.73$, $\beta = 1.73-1.74$, $\gamma = 1.73-1.744$. *Bustamite* has $2V = 44^\circ$; $\alpha = 1.66$ $\beta = 1.67$, $\gamma = 1.676$, n_x , n_y and X nearly 1 to $\{010\}$.



Franklin Furnace, N. J.

Comp. — Manganese metasilicate, $MnSiO_3$ or $MnO(SiO_3) = \text{Silica } 45.9$, manganese protoxide $54.1 = 100$. Calcium appears to be always present and may be a necessary constituent. It has been suggested that the formula might be written $CaMn_2Si_2O_{10}$. *Bustamite* has much more calcium than ordinary rhodonite, the material from Franklin, New Jersey, has the composition $CaMn_2Si_2O_{10}$. It also differs from rhodonite in its optical properties. There is evidence that there is a continuous series from rhodonite to bustamite with a gradual change in the optical properties. *Federite* is a variety with fine replacing manganese.

Pyr., etc. — H. B. Markens and faces with slight intumescence at 25° with the faces given near one for manganese. *Bustamite* gives with weak on charcoal a red up to 1000° . Slightly water soluble by acids. The rhodonite varieties often effervesce from traces of carbonate of calcium carbonate. In powder parts decompose in hydrochloric acid and the insoluble part consists of a white color. Darkens on exposure to the air, and sometimes becomes nearly black.

Diff. — Distinguished by its pink color, distinct cleavage, hardness, luster and manganese contents H. B.

Obs. — Rhodonite occurs in various manganese ore bodies, frequently associated with chrysotile, etc. It occurs in the Franklin district of the Lead Mine where it is found massive and also for structural purposes with tetrahedrite as happens also in Germany. In Italy at a single locality in Liguria. From Bolivia at Yacaré in department of Cochabamba. Considered at Ling-shih-tan in China, probably at the Hsinberg near Fencheng, northern Manchuria. In the case from Broken Hill, New South Wales. From Tientsin, North China. From Mexico, etc.

In the United States it occurs at Franklin, New Jersey, at the Franklin, Massachusetts, and some of the other localities. The variety *bustamite* occurs at Franklin, New Jersey, at the Franklin, Massachusetts, and some of the other localities. The variety *federite* occurs at Franklin, New Jersey, at the Franklin, Massachusetts, and some of the other localities. The variety *rhodonite* occurs at Franklin, New Jersey, at the Franklin, Massachusetts, and some of the other localities.

Names from color, name, and from the color. Rhodonite is often named *rhodonite* by introduction of the Mn as in *rhodonite*, *pyroxene*, also by *rhodonite*, *arabianite*, *rhodonite*, etc. further by introduction of CO_2 *rhodonite*, *rhodonite*, etc.

Use. — Rhodonite at times is used as an ornamental stone.

Pyroxmangite. A triclinic, manganese-iron pyroxene. In cleavage massive. Cleavages $\{100\}$ $\{010\}$ and $\{110\}$. In some $2V = 100^\circ$ $H = 5.5-6.5$ $G = 3.4-3.68$. Color yellow to dark brown. Easily fusible to a magnetic globule. Alters to *rhodonite*. Found near the Anderson in South Africa.

Rubingstonite. (After the name of the mine). In small black triclinic crystals near rhodonite in angle with $\{100\}$. Cleavages $\{100\}$ and $\{010\}$ also $\{001\}$ at times. $H = 5.5-6.5$ $G = 3.4-3.68$. Optically + $2V = 40-45^\circ$ $\alpha = 1.71$ $\beta = 1.70$ $\gamma = 1.72$. Darkens on exposure to air. Occurs at Herborn near Hildesberg, Hesse-Nassau, from Bayeno in Lago Maggiore, Piedmont, Italy. Found in distinct crystals at

at a comparatively low temperature. The occurrence in primitive rocks is due to the reduction of iron as it is oxidized. It is often seen in the form of a thin layer of iron ore in the rocks of the earth's crust. The iron ore is often found in the form of a thin layer of iron ore in the rocks of the earth's crust. The iron ore is often found in the form of a thin layer of iron ore in the rocks of the earth's crust.

In the United States in New York a *W. phoenicea* was taken in Lewis Co. at Blauvelt near Nesconong Bridge in abundance along with *Chrys. fulva* and *Chrys. flava*. In the Royal Kennebec Co. Maine, a very common form of *Chrys. flava* was taken in the Kennebec River in Kennebec Co. In the Kennebec River in Kennebec Co. Maine, a very common form of *Chrys. flava* was taken in the Kennebec River in Kennebec Co. In the Kennebec River in Kennebec Co. Maine, a very common form of *Chrys. flava* was taken in the Kennebec River in Kennebec Co.

[illegible]

PECTOLITE.

Mineralogic Axes: $a = b = c = 11140 \pm 0.9864$ $\beta = 84^\circ 40'$
 Continuity in close aggregations of acicular crystals recognized by X-ray
 C. rarely terminated. Enriched in Fe^{2+} and Fe^{3+} ions.
 Cleavage: (100) and (010) perfect. Hexagonal. Birefr. $H = 5$
 $G = 2.74-2.58$ faster to the surface of the crystal than to the interior.
 Color: white or grayish. Substrates color to opaque. Optic: $1 + 2$
 μ and $Z = 1.611$. Δ nearly ± 0.00 . $2V = 60^\circ$. $\alpha = 1.05$, $\beta = 1.00$
 $\gamma = 1.633$

Comp. $\text{HN}_3\text{As}_2\text{S}_6\text{O}$ or $\text{H}_2\text{O} \cdot \text{N}_2\text{O} \cdot 10\text{As}_2\text{O}_5 \cdot 8\text{SO}_3 = 8$ per 54.2, lime 33.8, soda 9.3, water 2.7 = 100.

The amount of water present varies and is in all cases of 1 ml. or more. The above form is best to use in cases where a small amount of water is present. May be used in any form present in a large amount of water.

Prv. 10 - 1. the more you sow, the more you will reap. B. L. Farnham 2. to a wheat crop. Do not sow a seed in the soil, do not sow with impurity, in of a man so a jelly. (After gives up)

Obs. I estimate the rate and the yield, based on reaction of systems in house every five
 minutes. I use a 100 ml. flask and a 100 ml. flask. I use a 100 ml. flask and a 100 ml. flask.
 The rate of reaction is determined by the amount of material and product, and with each
 five. It is a very simple method of estimating the rate.

[illegible]

Wednesday, 10th July 1913. The day was very hot and the sun shone brightly. We went to the beach and played for hours. The children were very happy and enjoyed the sand and sea. We also had a picnic under a big tree. The food was very good and we all enjoyed it. The day was very pleasant and we all had a good time.

[illegible]

Section 1: Let x and y be integers, $1 \leq x \leq 100$ and $1 \leq y \leq 100$. In particular, x and y are integers. Let $z = x + y$. If z is even, then z is a multiple of 2. If z is odd, then z is a multiple of 2 plus 1. In other words, z is either even or odd.

R. Schenck to
 at a ...
 in ...
 are very ...

| Monoclinic Section | | $a:b:c$ | β |
|--------------------|-----------------------------------------------------------------------|---------------------|---------|
| Amphibole | | 0.3511 : 1 : 0.2938 | 73° 58' |
| 1. | MgSiO ₃ | | |
| 2. CUMINGTONITE | (Mg, Fe)SiO ₃ | | |
| 3. GRUNERITE | (Fe, Mg)SiO ₃ | | |
| 4. TROMBITE | CaMg ₂ Si ₂ O ₇ | | |
| 5. ACTINOLITE | Ca(Mg, Fe ²⁺) ₂ Si ₂ O ₇ | | |
| 6. HORNBLITE | (K, Na ₂ , Mg, Ca, Mn)SiO ₃ | | |
| 7. HORNBLENDE | | | |

| | |
|----------------------|--------------------------------------------------------------------------|
| Feldspar | Contains molecules approximating to the following in varying proportions |
| Pyroxene | |
| Quartz in hornblende | |
| Basaltic hornblende | |

| | | $a:b:c$ | β |
|--------------|------------------------------------------------------------------------------------|---------------------|---------|
| Glaucofanite | Na(Al, Fe)Si ₂ O ₆ with (Mg, Fe)SiO ₃ | 0.53 : 1 : 0.20 | 75° |
| Riebeckite | Na ₂ (SiO ₃) ₂ with FeSiO ₃ | 0.5475 : 1 : 0.2295 | 76° 10' |
| Hastingsite | (Na, Na, Fe, Mg, Al, Fe)(OH) ₂ AlSi ₂ O ₆ | | |
| Arfvedsonite | Na ₂ Fe ₂ Al(OH) ₂ Si ₂ O ₆ | 0.5496 : 1 : 0.2975 | 75° 44' |

Triclinic Section

| | |
|------------|-------------------------------------------------------------------------|
| Enigmatite | (Fe, Na ₂)(Si, Ti)O ₃ Na(Al, Fe)SiO ₃ |
|------------|-------------------------------------------------------------------------|

The only species included under the triclinic section is the rare and imperfectly known enigmatite (cosynite).

The Amphibole Group embraces a number of species which, while falling in different systems, are yet closely related in form—as shown in the common prismatic cleavage of 54° to 56°—and in optical characters and chemical composition. As already noted (see p. 552) the species of this group form chemically a series parallel to that of the closely allied Pyroxene Group, and between them there is a close relationship in crystal-line form and other characters. The Amphibole Group, however, is less fully developed, including fewer species, and these known show less variety in form.

The chief distinctions between pyroxene and amphibole proper are the following: Pyroxene cleaves with pyroxene cleavage (54° to 56°) with amphibole cleavage (124°), the prismatic cleavage being much more marked in the latter.

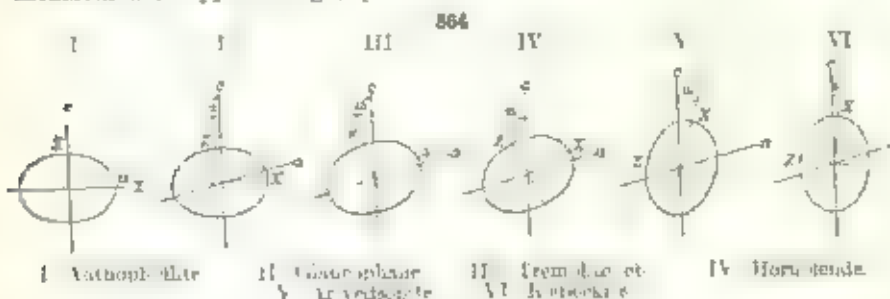
With pyroxene, crystals usually show prismatic and clinopyroxene cleavage of massive kinds, and a sharp, granular, well-defined, sharp crystal cleavage, chiefly along prismatic and clinopyroxene cleavage. In amphibole, the cleavage is less sharp.

The specific gravity of most of the pyroxene varieties is higher than that of the like varieties of amphibole. In composition, of course, the pyroxene group is a series of larger atoms in amphibole. The Mg is 1.1 in pyroxene, 1.1 in amphibole. A series more frequently play a prominent part in amphibole.

X-ray study has shown the structural relationships that exist between the pyroxene and amphibole groups. The amphibole structure can be derived by a reflection of the pyroxene structure over the plane (010). This results in giving a unit cell for amphibole which agrees with that of pyroxene except in the dimension parallel to the *b* axis. The *a* and *c* values of the corresponding dimension of the pyroxene cell. In pyroxene, as stated on p. 552, the silicon-oxygen tetrahedral groups are arranged in single chains parallel

to the c axis, whereas in amphibole the similar groups are united into double chains. These facts account for the crystalographic differences between the two groups, as for instance the difference between the respective cleavage angles. Further the joining of two silicon-oxygen chains together reduces the silicon-oxygen ratio to $2:3:1$ instead of $8:3:1$, as in pyroxene. The positions of the various metal-magnesium atoms in the structure are similar to their positions in the pyroxene series (see p. 552).

The optical relations of the pyroxene members of the group, as regards the position of the crystallographic axes, as exhibited by the following figures (Cross; compare Fig. 837, p. 552, for a similar representation for the corresponding members of the pyroxene group).



Orthorhombic Section

ANTHOPHYLLITE.

Orthorhombic. Axial ratio $a : b = 0.5147 : 1$. Crystals rare, habit prismatic $\{110\}$ & $\{1\bar{1}0\} = 53^\circ 23'$. Commonly in slender, or large radiating fibers, often very slender in aggregations of prisms.

Crystals prismatic perfect, but less so, & 100 sometimes distinct. $H = 5.5-6$. $G = 2.85-3.2$, increasing with percentages of iron. Lustre vitreous, somewhat pearly on the cleavage face. Color brownish gray, yellowish brown, clay-brown, brownish green, mineral-green, sometimes iridescent. Streak unaltered or grayish. Transparent to subtransparent. Sometimes glassy, $X = Y = Z$ or Z = pale yellow-green. Ax. $\parallel b(010)$. $Z = c$ axis. $2V$ near 90° (broad), \pm in anthophyllite, \pm in gedrite. For artificial Mg $_{100}$, $\alpha = 1.684$, $\beta = 1.597$. γ varies with 27 per cent. FeSiO $_3$, $\alpha = 1.633$, $\beta = 1.612$, $\gamma = 1.657$, for higher percentages of FeSiO $_3$, γ may rise to 1.698.

Comp. \pm Mg Fe Si O $_3$ corresponding to clinochlore, hypersthene in the pyroxene group. Also contains sometimes appreciable amount of iron. There is the same relation in optical characters between anthophyllite and gedrite as between enstatite and hypersthene of Figs. 839, 840, p. 553.

Var. **ANTHOPHYLLITE**. Mz Fe = 4 to 3 to 1 etc. For 2 to 1 the percentage composition is SiO_2 55.0, FeO 44.9, O 5.1, approx. $d_{25} = 1.70$. Anthophyllite sometimes occurs in a form resembling actinolite.

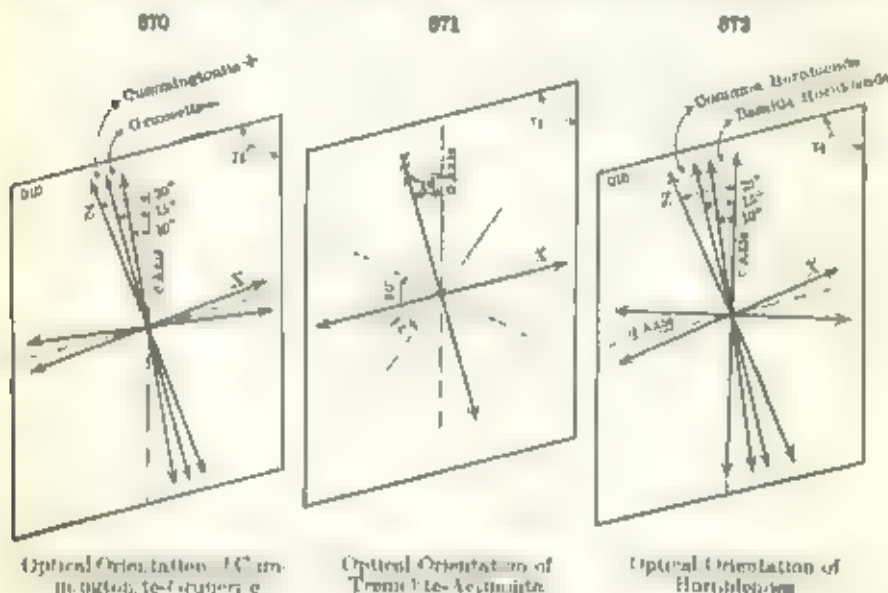
It is not very abundant in nature, and is more abundant in the laboratory. It corresponds near 4 to 5 to typical hornblende, and is a member of the hornblende group.

It is found in the same rocks as hornblende, or greenish hornblende, in the same rocks. Africa, intermediate between the hornblende and green hornblende, is a member of the hornblende group.

Perthanthophyllite is a name given to an iron anthophyllite from Canada and elsewhere.

fibrous varieties often silky. Color between black and white, through various shades of green, inclining to blackish green—also dark brown, rarely yellow, pink, rose-red. Streak uncolored or paler than color. Sometimes nearly transparent—usually subtransparent to opaque.

Pleochroism strongly marked in all the deeply colored varieties, as described beyond. Absorption usually $Z > Y > X$. Optically —, rarely +. Ax pl usually $b(010)$. Extinction angle on $b(010)$, or $Z \wedge c$ axis = $+15^\circ$ to 18° in most cases, but varying from about 1° up to 37° , higher angles in



rare instances. Hence also $Bx \wedge c$ axis = -75° to -72° , etc. See Figs. 870-872. Dispersion $\rho < \sigma$. Axial angles variable, see beyond.

Optical characters, particularly indices of refraction, birefringence and extinction angles vary with change in composition, particularly with the total amount of iron present. In general the indices and extinction angles decrease with increase of iron content while the birefringence decreases.

Comp. — In part near to a normal metasilicate of calcium and magnesium, $RSiO_3$, usually with iron, also manganese and thus in general analogous to the pyroxenes. As stated on p. 568 the silicate oxygen ratio corresponds to Si_2O_6 , instead of Si_2O_5 . The alkali metals, sodium and potassium, also present, and in proportion so than with pyroxene. In part also aluminous, corresponding to the aluminous pyroxenes. Titanium sometimes is present and also rarely fluorine in small amount. Water is considered as an essential constituent.

The problem of the composition of the amphiboles is a complex one and has been the object of much study. Extensive replacements of one element by another may take place, giving rise to a wide variety in chemical composition. It is impossible to summarize here the various interpretations of the composition that have been offered in the past or

even to indicate all the views that different mineralogists hold at present. See p. 569 and further under the different varieties described below.

1 **MgSiO₃**. An amphibole of this composition and corresponding to clinoclasite of the Pyroxene Group is of doubtful natural occurrence. It has, however, been prepared artificially. It would form the theoretical end member of the various amphibole series in which the molecules FeSiO₃, MnSiO₃, and CaSiO₃ appear in isomorphous relations.

The name *kappferite* was originally given to what was thought to be a monoclinic amphibole largely composed of MgSiO₃. Later it was assumed that the mineral in question was orthorhombic and it was accordingly named *actinolite*. When the orthorhombic molecule MgSiO₃ was described it was named *actinolite*. Later the name *kappferite* was shown to be incorrect as an originally lower end and the name was restored to be monoclinic MgSiO₃. However, new analyses of the original *kappferite* show that it is more properly classed as an actinolite.

2 **Cummingtonite** (Mg, Fe, SiO₃). The magnesium and iron replace each other in varying amounts and the mineral grades into grunerite. Small amounts of manganese may be present. The range in composition of the cummingtonite-grunerite series is from about 70 per cent MgSiO₃ and 30 per cent FeSiO₃ to nearly 100 per cent FeSiO₃. The name *cummingtonite* is commonly restricted to that portion of the series containing between 50 and 70 per cent MgSiO₃. Usually fibrous or fibro-lamellar, often radiated. Color varies from about 3.1 to 3.6 for grunerite. Color brown. $Z \wedge c$ axis = 20° to 15° decreasing with increase in percentages of FeSiO₃. Optically — 2V large. $\rho < \nu$. Indices for nearly equal mixtures of MgSiO₃ and FeSiO₃ are: $\alpha = 1.64$, $\beta = 1.65$, $\gamma = 1.67$. These values increase with increasing percentages of iron.

3 **Grunerite** (Fe, Mg, SiO₃). The percentages of FeSiO₃ range from 50 to 100 per cent. MgSiO₃ may also be present in considerable amounts. See further under cummingtonite, above. Commonly fibrous or lamellar. $G = 3.4-3.6$. Color brown. Silky luster. $Z \wedge c$ axis = 15° to 10°, decreasing with increase in percentage of FeSiO₃. Optically — 2V large. $\rho > \nu$. $\alpha = 1.680$, $\beta = 1.707$, $\gamma = 1.726$ (for pure FeSiO₃). The values decrease regularly with increasing percentages of the iron molecule, also the presence of manganese replacing the iron changes slightly the indices.

Dannemoraite is a manganeseiferous member of the cummingtonite-grunerite series from Dannemora, Upson, Sweden. Colorless or fibrous. Color yellowish brown to greenish gray. $G = 3.4-3.5$. $Z \wedge c$ axis about 14°. Axial angle large.

4 **Tremolite** (Calcium, nephrite, nephrite, a part). *Calcium-magnesium amphibole*. Formula has commonly been given as $\text{CaMg}_3\text{Si}_2\text{O}_{12}$, but from a study of the atomic structure by means of X rays it is shown that the composition is more accurately given by the formula $(\text{Ca}, \text{Mg}, \text{Fe})\text{Si}_2\text{O}_{12}$. Ferric iron occurs replacing the magnesium, tremolite thus grading into actinolite. Small amounts of other molecules involving alkalies may also be present. Colors white to dark gray. In distinct crystals, either long-bladed or more rarely short and stout. In aggregates long and thin columnar, or fibrous, also sometimes granular massive nephrite, below. $G = 2.9-3.2$. Sometimes transparent and colorless. Optically — Extinction-angle on $b(11)$, or $Z \wedge c$ axis = +16° to 15°, hence $Bx \wedge c$ axis = -74° to -72°. $2V = 80^\circ$ to 88° . $\alpha = 1.60$, $\beta = 1.61$, $\gamma = 1.62$ for nearly pure tremolite, the values increasing with increase of the actinolite molecule.

[illegible]

6. **RIGHTSIDE.** An amphibole containing MgO (18 to 21 per cent), CaO (5 to 8 per cent), MnO (5 to 12 per cent), alkali oxides (5 to 9 per cent),

[illegible]

L. magnifica is a weak-absorbent, related to *axia-magnifica* in the previous lesson.

7 ALUMINOSA AMPHIBOLE Hornblende. Contains aluminas or ferric iron, and usually both with ferric iron, secreted as ~~iron~~ magnesian calcian, and alkalis. Hydroxy and fluorine are usually present in small amounts, also chlorine in many varieties. The color of hornblende here just described ranges from the lightest pistachio, rather tinged by blue iron, through the light to dark green, purplish, to the dark-colored or black hornblende, the color growing darker with increase in amount of iron. ~~Color~~ ^{Color} varies from 0° to 37°, see below. Fracture strong. Absorption usually $X < Y < Z$.

Faintly: *Aluminum Magnesium Sulfate Amorphous* Color white - gray and easily
 granular and has a taste of *Aluminum Sulfate* and a taste of *Aluminum Sulfate*
 and is the same as *Aluminum Sulfate* but is a white granular substance
 colored with a blue tinge.

the Russian mineralogist, von Kozlovskiy.

[illegible][illegible]

Harelda = greenish yellow; *Z* = pale or light brown; *A* = pale or light brown; *B* = greenish yellow; *C* = light brown; *D* = light brown; *E* = light brown; *F* = light brown; *G* = light brown; *H* = light brown; *I* = light brown; *J* = light brown; *K* = light brown; *L* = light brown; *M* = light brown; *N* = light brown; *O* = light brown; *P* = light brown; *Q* = light brown; *R* = light brown; *S* = light brown; *T* = light brown; *U* = light brown; *V* = light brown; *W* = light brown; *X* = light brown; *Y* = light brown; *Z* = light brown.

New York 2. A slender, dark brown to black, highly branched from the base, in 1 cm. green
rosette. The leaves are small, narrow, linear, with a dark green, glaucous, or
blue-green, waxy, or slightly waxy, surface. The stem is 2-3 cm. to
10' tall. The leaves are 1-2 cm. long, 1-2 mm. wide, and are
green. Z = dark brown, black, or dark green. Hatched from larvae with 5
concentric rings and a dark brown or black center.

Some of the horridlede from the ac-m. de-mo-n rocks of Krasinsky in the northern Ural Mts.

S. mellea, from Travancor, India, is an interesting one in the strong phosphorescence, $\lambda = 4500$ Å, and with $n_D^{20} = 1.5000$, $n_D^{25} = 1.4990$.

It appears to be the only book of its kind in the world.

This plate from Philadelphia, Sweden, is an iron-magnesium sulphide showing unusual dichroism.

Isomeric to a dark-colored
brown. A dark angle very small
3.5 mm

Hydroxide is described as an amphibole intermediate between hornblende and glaucophane.

It is a chloride in a magnesium-calcium atmosphere, poor in Fe but rich in molybdenum and water.

For
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873

and by having parallel clea

The atmosphere have shown that the temperature is going to be in the 70's and 80's. The humidity is going to be in the 60's and 70's. The wind is going to be in the 10's and 20's. The clouds are going to be in the 20's and 30's. The visibility is going to be in the 10's and 20's. The weather is going to be in the 10's and 20's. The temperature is going to be in the 70's and 80's. The humidity is going to be in the 60's and 70's. The wind is going to be in the 10's and 20's. The clouds are going to be in the 20's and 30's. The visibility is going to be in the 10's and 20's. The weather is going to be in the 10's and 20's.

[illegible][illegible][illegible]

Obs.—Beryl is most commonly found in granite rocks, either in druses in the granite or in pegmatite veins. It has also been found in the age of a chertous quartzite. The mineral is common in the older rocks of the Himalayas, and in the type of the granite.

[illegible][illegible]

$\frac{1}{2} \log \frac{1}{2} + \frac{1}{2} \log \frac{1}{2} = \frac{1}{2} \log \frac{1}{4} = -\frac{1}{2} \log 4 = -1$

[illegible]

The first part of the paper is devoted to the study of the asymptotic behavior of the solutions of the system (1) for large values of the parameter λ . It is shown that the solutions of the system (1) for large values of λ are asymptotically equivalent to the solutions of the system (2). The second part of the paper is devoted to the study of the asymptotic behavior of the solutions of the system (1) for small values of the parameter λ . It is shown that the solutions of the system (1) for small values of λ are asymptotically equivalent to the solutions of the system (3).

Calcareous. It is more abundant than elsewhere in the plateau because of its high position. It is a very hard, crystalline, and is not easily broken. It is a very hard, crystalline, and is not easily broken. It is a very hard, crystalline, and is not easily broken. The mineral is also reported from Mugers Cove, near Hot Springs, Garland Co., Arkansas.

MUMMISOITE. A titanium-iron-calcium silicate of sodium, iron, manganese, and calcium. In tabular masses. Mohs as cleavage. Lustrous. Color violet. $d = 1.35$, $H = 2.5$. From La Jara and Hilma, Tadmora, Kala Namak, northern Russia.

Cappelentite. A hexamorphite of titanium and barium. Hexagonal, rhombohedral in growth, brown prismatic crystals. $H = 6$, $d = 1.45$. Lustrous. Optically — $a = 1.72$, $b = 1.72$, $c = 1.72$. From the Langeberg district, southern Norway.

Melanocerite. A hexamorphite of the silicate of barium, calcium, and cerium. Rhombohedral. $H = 5.5$, $d = 1.45$. Lustrous. Optically — $a = 1.72$, $b = 1.72$, $c = 1.72$. From the Langeberg district, southern Norway.

Caryocrite. A hexamorphite, containing Fe, Mn, and Ca. Hexagonal, rhombohedral. Tabular. $H = 5.5$, $d = 1.45$. Lustrous. Optically — $a = 1.72$, $b = 1.72$, $c = 1.72$. From the Langeberg district, southern Norway.

Steinstrupite. A hexamorphite of the silicate of barium, calcium, and cerium. Rhombohedral. $H = 5.5$, $d = 1.45$. Lustrous. Optically — $a = 1.72$, $b = 1.72$, $c = 1.72$. From the Langeberg district, southern Norway.

Tronite. A hexamorphite of the silicate of barium, calcium, and cerium. Rhombohedral. $H = 5.5$, $d = 1.45$. Lustrous. Optically — $a = 1.72$, $b = 1.72$, $c = 1.72$. From the Langeberg district, southern Norway.

Leucophanite. A hexamorphite of the silicate of barium, calcium, and cerium. Rhombohedral. $H = 5.5$, $d = 1.45$. Lustrous. Optically — $a = 1.72$, $b = 1.72$, $c = 1.72$. From the Langeberg district, southern Norway.

Melaphanite. A hexamorphite of the silicate of barium, calcium, and cerium. Rhombohedral. $H = 5.5$, $d = 1.45$. Lustrous. Optically — $a = 1.72$, $b = 1.72$, $c = 1.72$. From the Langeberg district, southern Norway.

Actinolite. A hexamorphite of the silicate of barium, calcium, and cerium. Rhombohedral. $H = 5.5$, $d = 1.45$. Lustrous. Optically — $a = 1.72$, $b = 1.72$, $c = 1.72$. From the Langeberg district, southern Norway.

The two following minerals are very similar to each other and should possibly be considered as one.

Cordierite. A hexamorphite of the silicate of barium, calcium, and cerium. Rhombohedral. $H = 5.5$, $d = 1.45$. Lustrous. Optically — $a = 1.72$, $b = 1.72$, $c = 1.72$. From the Langeberg district, southern Norway.

Diopside. A hexamorphite of the silicate of barium, calcium, and cerium. Rhombohedral. $H = 5.5$, $d = 1.45$. Lustrous. Optically — $a = 1.72$, $b = 1.72$, $c = 1.72$. From the Langeberg district, southern Norway.

Diopside. A hexamorphite of the silicate of barium, calcium, and cerium. Rhombohedral. $H = 5.5$, $d = 1.45$. Lustrous. Optically — $a = 1.72$, $b = 1.72$, $c = 1.72$. From the Langeberg district, southern Norway.

CORDIERITE. Lith. Diopside.

Orthorhombic. Axes $a = 0.5871$, $b = 0.5585$. X-ray study of structure indicates possibility of triclinic symmetry.

Twins: tw pl on (110), also of (100), both yielding pseudo-hexagonal forms.

A number of basic orthosilicates are here included, which yield water upon ignition, also some which are more or less basic. These include such as the sodalite which are of secondary origin and here made a consideration because of their relation to other natural salts. The Microcline group is so closely related to the feldspar group that it is included with the feldspar, and some of the other orthosilicates later with them.

Nephelite Group. Hexagonal.
Sodalite Group. Isometric.
Helvite Group. Isotetrahedral.
Garnet Group. Isometric.
Chrysolite Group. Orthorhombic.
Phenacite Group. Trirhombohedral.

Scapolite Group. Tetragonal-pyramidal.
Zircon Group. Tetragonal.
Danburite Group. Orthorhombic.
Datolite Group. Monoclinic.
Epidote Group. Monoclinic.

Nephelite Group. Hexagonal

| | Typical formula RAlSi_3O_8 | |
|-----------------------------------|----------------------------------------------------------------------------------------|------------------------------------------------|
| Nephelite | $\text{NaAlSi}_3\text{O}_8$ | $c = 0.9389$ |
| Soda-nephelite, artificial | $\text{Na}_4\text{Al}_2\text{Si}_6\text{O}_{20}$ | |
| Encrypsite | $\text{LiAlSi}_3\text{O}_8$ | Kalophyllite KAlSi_3O_8 |
| Cancrinite | $\text{H}_2\text{Na}_2\text{Al}_2(\text{NaCO}_3)_4(\text{SO}_4)_2$ | $2c = 0.9448$ |
| Microsummite | $(\text{Na}, \text{K})_4\text{Al}_2\text{Si}_6\text{O}_{20} \cdot 2\text{H}_2\text{O}$ | $2c = 0.9367$ |

The species of the NEPHELITE GROUP are hexagonal in crystallization and have in part the typical orthosilicate formula RAlSi_3O_8 . From this formula nephelite itself deviates somewhat, though an artificial soda-nephelite, $\text{Na}_4\text{Al}_2\text{Si}_6\text{O}_{20}$, conforms to it. The species cancrinite and microsummite are related in formula and also in composition, though in the latter respect somewhat complex. They serve to connect this group with the sodalite group following.

NEPHELITE. Nephelina. Eleolite.

Hexagonal-hemimorphic (p. 148). Axis $c = 0.93893$. The structure of nephelite corresponds to normal hexagonal symmetry. It is only in its etch figures that triclinic symmetry is suggested.

In thick six- or twelve-sided prisms with plane or modified summits. Also massive compact and in embedded grains, structure sometimes then columnar.

Fracture conchoidal, distinct, $\{10\bar{1}0\}$ imperfect. Fracture subconchoidal. Brittle. $H = 5.5-6$. $G = 2.55-2.65$. Luster vitreous to glassy, a little opalescent in some varieties. Colorless white or yellowish, also, when massive, dark green, greenish or bluish gray, brownish red and brick red. Transparent to opaque. Optically — Birefringence low and variable. $\alpha = 1.536-1.549$, $\epsilon = 1.532-1.544$.

Var. 1 Nephelite. Glassy. Found in small glassy crystals or grains, transparent with vitreous luster, first found on Mt. Soudon, Vermont. Characteristic anorthoclase of younger age place like anorthoclase. **2 Eleolite.** In large coarse crystals or more commonly massive, with a glassy luster, and red, blue, green, or gray in color. Usually clouded by minute inclusions. Characteristic of granular crystalline rocks, syenites, etc.

Comp. — $\text{NaAlSi}_3\text{O}_8$. This is the composition of the artificial mineral. Natural nephelite always contains silica in varying excess and also small amounts of potash. The composition usually approximates to $\text{Na}_2\text{K}_2\text{Al}_2\text{Si}_6\text{O}_{20}$.

Synthetic experiments, showing crystals like nephelite with the composition $\text{NaAlSi}_3\text{O}_8$, lead to the conclusion that a natural nephelite could be an isomorphous mixture of nephelite and quartz. The presence of potash in nephelite is due to the fact that KAlSi_3O_8 is more soluble than nephelite, and is more easily separated from the solution. The presence of potash in nephelite is due to the fact that the solubility of nephelite is greater than that of quartz, and is more easily separated from the solution. The presence of potash in nephelite is due to the fact that the solubility of nephelite is greater than that of quartz, and is more easily separated from the solution.

Artificial nephelite is not subject to changes in composition at 248°C . This is because it is a pure substance. The natural nephelite, however, is a mixture of nephelite and quartz, and is subject to changes in composition at 248°C .

Pyx., etc. Btl. forms quartz, SiO_2 , a colorless glass, coating the inner yellow. Contains with soda.

Dist. The nephelite is a glassy substance with a high refractive index. It is a colorless glass, coating the inner yellow. Contains with soda.

Micro. The nephelite is a glassy substance with a high refractive index. It is a colorless glass, coating the inner yellow. Contains with soda.

Art. Nephelite is a glassy substance with a high refractive index. It is a colorless glass, coating the inner yellow. Contains with soda.

Obs. — Nephelite is a rather widely distributed mineral. It is a colorless glass, coating the inner yellow. Contains with soda.

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Eucryptite — $\text{LiAlSi}_3\text{O}_8$. In symmetrically arranged crystals hexagonal, embedded in a glassy material. The crystals are of a colorless glass, coating the inner yellow. Contains with soda.

Ontario. Also in fine large masses with blue color on Ice River a tributary of the Beaverfoot, near Kicking Horse Pass, British Columbia.

Hackmanite. A solid crystalline mass, 6 per cent of the chloride $3\text{NaAlSi}_3\text{Cl}_6$, is present in a rock which comes from the lower valley of the Kaskapau near Laramie. Color reddish-brown with shades on exposure to light. $n = 1.48$.

ANALYTICAL. A silicate of sodium and aluminum with a small amount of chlorine, approximately $\text{Na}_2\text{O} = 44.6$, $\text{Al}_2\text{O}_3 = 12.50$. It contains a trace of water but is not hygroscopic and higher than solid ice. Occurs as grains and minute crystals in phonolites of Canada, New Zealand.

HAUYNITE. Hauynite.

Isomorphism. Sometimes in dodecahedrons, octahedrons, etc.

Twins. (see pl. 611) contact-twins also polysynthetic penetration-twins (Fig. 431 p. 187). Commonly in rounded grains, often looking like crystals with fused surfaces.

Cleavage. dodecahedral rather distinct. Fracture flat conchoidal to uneven. **Brach.** $H = 5-6$. $G = 2.4-2.5$. Luster vitreous to somewhat greasy. Color bright blue, sky-blue, greenish blue, asparagus-green,

879



Sections of crystals of hauynite after Mohr

red, yellow. Streak slightly bluish to colorless. Subtransparent to transparent, often enclosing symmetrically arranged inclusions (Fig. 879). $n = 1.400$.

Comp. — $3\text{NaAlSi}_3\text{O}_8, \text{CaSO}_4$. Silica 32.0 sulphur trioxide 14.2, alumina 27.2 (see 100) soda 16.8 = 100. The molecules KAlSi_3O_8 and $\text{CaAl}_2\text{Si}_2\text{O}_7$ may also be present in small amounts.

Pyx., etc. In the closed tube retains its color. H.F. on the forceps fuses at 4-5 to a white glass, soluble in hydrofluoric acid and decomposes with evolution of sulphur dioxide. The solution gives a test for the sodium which is given with barium chloride.

Micro. — Similar to sodalite, which see.

Artf. — Has been produced artifiially in the same ways as with sodalite with the use of a phosphate instead of a borate.

Obs. — Hauynite occurs as rocks especially in the extensive types. Commonly in rocks that are volcanic and rich in soda and calcium, associated with nepheline, etc.

In Italy hauynite occurs in the Vesuvius district. Microscopic Microscopic in the west of North America, in various spots in the lavas of the San Juan region, in the Lake district, Canada, at Souderton, Ill., Lanier, Tex., etc., on the Hawaiian Islands.

Noseite. Named after hauynite but contains the or no iron. $3\text{NaAlSi}_3\text{O}_8, \text{Na}_2\text{SO}_4$. Color grayish, bluish, greenish, sometimes colorless, due to the presence of inclusions of Fig. 879. $H = 5-6$. $G = 2.3-2.4$. $n = 1.48$. **Artf.** — Same as above made of an artificial base containing an heavy metal. Found in Lanier, Tex., the Lake district of Illinois, from the Hawaiian Islands. From Vesuvius, south of Italy. From the phonolites of Catal, France. Found in the lavas of the Canary and Cape Verde Islands.

LAZURITE. Lazurite. Lazurite.

Isomorphism. In cubes and dodecahedrons. Commonly massive compact. **Cleavage.** dodecahedral, imperfect. Fracture uneven. $H = 5-5.5$.

$G = 2.38-2.45$ Luster vitreous. Color rich Berlin-blue or azure-blue, violet-blue, greenish blue. Transparent. $n = 1.500$.

Comp. Essentially $3\text{Na}_2\text{Al}_2\text{Si}_2\text{O}_{10} \cdot \text{N}_2\text{S}$, but containing also in isomorphous combination the magnate and sodalite molecules. The character of the sulphur radical is uncertain since in artificial ultramarine it may be Na_2S , Na_2S_2 , or Na_2S_4 .

The heterogeneous character of what had long passed as a single mineral under the name lapis lazuli was first shown by Brogger (1902) in his paper on the Ultramarine Group. The necessary material was obtained from a Brogger and Löfgren in the collection of the University of Stockholm. Brogger is a geologist and a mineralogist, and Löfgren a chemist. They have shown that the lapis lazuli is a mixture of several minerals, and that the blue color is due to the presence of a certain amount of iron in the structure. The discovery of the Ultramarine Group has led to a re-examination of the lapis lazuli from various localities, and it is now known that it is a mixture of several minerals, and that the blue color is due to the presence of a certain amount of iron in the structure. Brogger is a geologist and a mineralogist, and Löfgren a chemist. They have shown that the lapis lazuli is a mixture of several minerals, and that the blue color is due to the presence of a certain amount of iron in the structure.

Micro. — See description of the mineral.

Pyr. etc. Heats in the heat and gives off some moisture. The variety from Chile gives a blue color when heated, but the color of the mineral remains the same when heated. It is soluble in concentrated hydrochloric acid and yields granular crystals of iron pyrites and iron pyrites.

Obs. The lapis lazuli is a common mineral in the Alps, and is found in the mountains near the city of Innsbruck. It is also found in the mountains near the city of Salzburg.

The Ultramarine Group is a group of minerals which are found in the Alps, and are characterized by their blue color. The group includes the minerals Helvite, Danalite, Eulytite, and Zuytite. These minerals are found in the Alps, and are characterized by their blue color. The group includes the minerals Helvite, Danalite, Eulytite, and Zuytite. These minerals are found in the Alps, and are characterized by their blue color.

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Helvite Group. Isometric-tetrahedral

| | |
|----------|------------------------------------------------------------------|
| Helvite | $3 \text{ Mn, Fe, BeSiO}_3, \text{MnS}$ |
| Danalite | $3 \text{ Fe, Zn, Mn, BeSiO}_3, \text{ZnS}$ |
| Eulytite | BaSiO_3 |
| Zuytite | $(\text{Al, Mn, Fe, Cl})_2 \text{ Al}_2\text{Si}_2\text{O}_{10}$ |

The Helvite Group includes several rare species isometric-tetrahedral in crystallization and in composition and structure related to the species of the Sodalite Group.

HELVITE.

Isometric-tetrahedral. Commonly in tetrahedral crystals, also in spherical masses. The atomic structure is similar to that of sodalite. The unit cell contains two molecules.

Cleavage octahedral in traces. **Fracture** uneven to conchoidal. **Brittle**. $H = 4-5$. $G = 3.4-3.55$. Luster vitreous, passing to resinous. Color honey yellow, passing to yellow brown, and dark green, reddish brown. Struck in color red. **S.** transparent. $n = 1.739$. **Pyrænetic**.

Comp. $3 \text{ Mn, Fe, BeSiO}_3, \text{MnS}$

Pyr. etc. Fuses at 3. R.F. with interference to a yellowish brown. Sp. in hand, being a little in R.F. W. the blue color is due to the reaction of the iron pyrites with the iron pyrites.

Obs. Helvite is found in veins with quartz, barite, and iron ore and in pegmatite veins. Also found as grains in gneiss.

Found in the Thiem Mts., Russia, near Musk in large spherical masses in pegmatite. In Rammelsberg-Kassakharany in Saxony at Riesa and also near Schwettersberg in gneiss. In Norway from the a. g. gneisses at various places in the Fangerfjord district. In the United States at the mica mines near Amelia Court House, Amelia Co., Virginia. Named by Werner in allusion to its violet color, from *amethystos*.

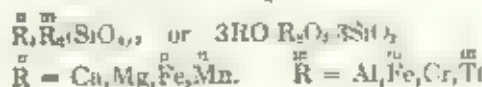
Danaitite $\text{Fe}_2\text{ZnMg}(\text{BO}_3)_2\text{ZnSi}_2$. In octahedrons usually massive. $H = 5.5-6$. $G = 3.427$. Color reddish to gray. $n = 1.774$. Occurs in lower Co. Massachusetts, in small granular masses in the Rockport granite tape and with magnetite and quartz at Chester, Mass. at Hartlett. Common in New Hampshire. Reported from West Cheyenne Canon, El Paso Co., Colorado. Found also at Redoubt, Alaska.

Eulytite Ba_2SiO_4 . Isolated in minute tetrahedral crystals also in spherical forms. X-ray study shows that structure is of unit cell. $H = 4$. $G = 6.1$. Color white to brown. In granular masses, w. or colorless. $n = 2.405$. Found in Saxony with native hematite near Schneeberg, also at Johanngeorgenstadt, near quartz and quartzite.

Zunyite $\text{Al}_2\text{Fe}_2(\text{SiO}_3)_4$. Minute crystals of aluminum, approx. AlOILFeCl_2 . Also in opaque translucent tetrahedrons. $H = 7$. $G = 2.873$. $n = 1.46$. Occurs in peg. by Johnson in masses near Posttownship, South Africa. From the Zuni mine, near Silverton, San Juan Co., and on Red Mountain, Garay Co., Colorado.

Agricolite. — Same as for eulytite, Ba_2SiO_4 , but monocryst. Fibrous. In globular or semi-globular forms. $n = 2.40$. In Saxony at Johanngeorgenstadt and Schneeberg.

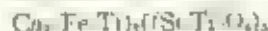
4. Garnet Group. Isometric



Garnet

| | | | |
|----------------|------------------------------------------|-------------|------------------------------------------|
| A GROSSULARITE | $\text{Ca}_3\text{Al}_2(\text{SiO}_3)_4$ | E ANDRADITE | $\text{Ca}_3\text{Fe}_3(\text{SiO}_3)_4$ |
| B PYROPE | $\text{Mg}_3\text{Al}_2(\text{SiO}_3)_4$ | Also | $(\text{Ca, Mg, Fe})_3\text{SiO}_3$ |
| C ALMANDINE | $\text{Fe}_3\text{Al}_2(\text{SiO}_3)_4$ | | $(\text{Ca, Fe})_3\text{SiO}_3$ |
| D SPESSEARITE | $\text{Mn}_3\text{Al}_2(\text{SiO}_3)_4$ | F UVAROVITE | $\text{Ca}_3(\text{Cr, SiO}_3)_4$ |

Schorlomite

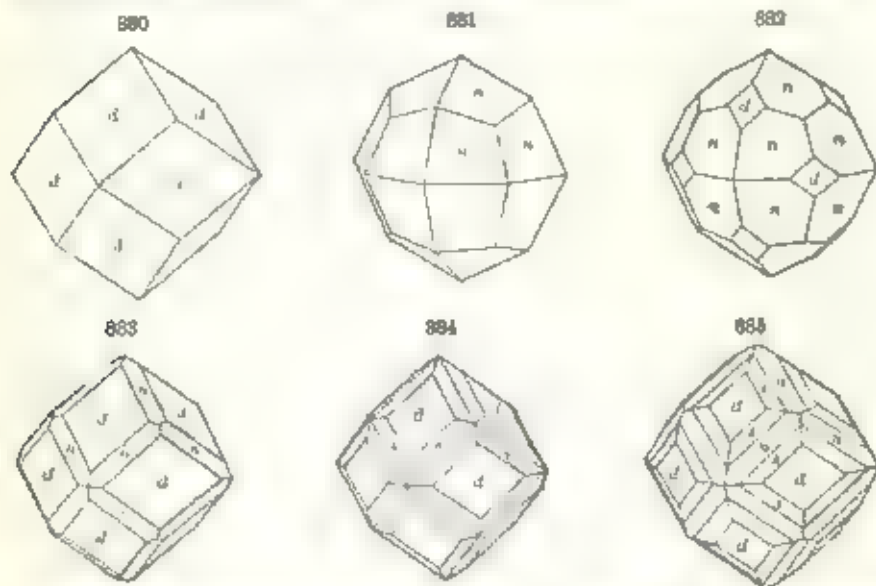


The GARNET GROUP includes a series of important sub-species included under the same specific name. They all crystallize in the normal class of the isometric system and are alike in habit, the dodecahedron and trapezohedron being the common forms. They have also the same general formula, and while the elements present differ widely there are many intermediate varieties. Some of the garnets include titanium replacing iron, and these they are connected with the rare species schorlomite, which probably also has the same general formula.

GARNET.

Isometric. The dodecahedron and trapezohedron are the common simple forms, also these in combination, or with the hexoctahedron and cube. Cubic and octahedral faces rare. Often in irregular embedded grains. Also massive, granular, coarse or fine and sometimes fibrous, lamellar, lamellar thick and bent. Sometimes compact cryptocrystalline like nephrite. X-ray study of the atomic structure shows a complicated arrangement containing eight molecules. The SiO_3 groups are independent of each other, the R atoms lie in the center of a group of six oxygen atoms and the R atoms in the center of a group of eight oxygen atoms.

Parting $d(110)$ sometimes rather distinct. Fracture subconchoidal to uneven. Brittle (or sometimes friable) when granular massive, very tough when compact cryptocrystalline. $H = 6.5-7.5$. $G = 3.15-4.3$, varying with the composition. Luster vitreous to resinous. Color red, brown, yellow, white, apple green, black, and a red and green, colors often bright. Streak white. Transparent to subtranslucent. Often exhibits anomalous double refraction.



respectively grossularite, almandine, and spessartine (see Art. 441). Refractive index rather high, and varying considerably with the composition. The different pure minerals have approximately the following indices:

Pyrrope 1.705, Grossularite 1.715, Spessartine 1.700, Almandine 1.830, Uvarovite 1.870, Annabergite 1.945.

Comp. — An orthoester having the general formula $(R,R')_3(SiO)_3$, or $3(R,R')SiO_3$. The divalent cations may be calcium, magnesium, ferrous iron or manganese. The trivalent cations, aluminum, ferric iron or chromium, rarely titanium. Further, silicon may sometimes be replaced by titanium. Different garnet molecules are isomorphous with each other although there are generally, quite limits to their miscibility. The isomorphism will be found to have two or three component molecules in the case, however, where three are present and is commonly in subnormal amount. It has been pointed out that the garnet may be considered as consisting of two polymorphic series, a pyrope-dialyspessartine series, and a grossularite-almandine series. These two have but only a slight miscibility with each other. The index of refraction and specific gravity vary directly with the variation in composition.

Var. — There are three main groups, and various subdivisions under each, many of these blending into each other.

1. Aluminum Garnet, including

- | | | | |
|---|----------------------|------------------------------------------|------------------------------------------|
| A | GROSSULARITE | Calcium-Aluminum Garnet | $\text{Ca}_3\text{Al}_2(\text{SiO}_4)_3$ |
| B | Pyrope | Magnesium-Aluminum Garnet | $\text{Mg}_3\text{Al}_2(\text{SiO}_4)_3$ |
| C | Iron-Aluminum Garnet | $\text{Fe}_3\text{Al}_2(\text{SiO}_4)_3$ | |
| D | Spessartite | Manganese-Aluminum Garnet | $\text{Mn}_3\text{Al}_2(\text{SiO}_4)_3$ |

II. Iron Garnet, including

1. As RADITE Calcium-iron CURSE $(Ca, Fe)_2SiO_4$
 (1) Ordinary (2) Magnesian (3) Lustrous (4) Lustrous

III. Chromium Garnet

- | | | | |
|---|-----------|-------------------------|--------------------------------------------------------|
| Е | Улановитт | Calcium-Chromium Garnet | $\text{Ca}_3(\text{Cr, Mn})_2\text{Si}_2\text{O}_{12}$ |
|---|-----------|-------------------------|--------------------------------------------------------|

The name *lupinus* is from the Latin *lupinus*, meaning like a green and broad-leafed podage tree, the seeds of which are small, in number and size, as a bean to the aspect of the contrast.

A. GROSSULARITE. Essonite or Hessonite. Calcium garnet. Formula $\text{Ca}_{10}(\text{Al}, \text{Fe})_6\text{Si}_8\text{O}_{48}$, $n_x = 1.70$, $n_y = 1.69$, $n_z = 1.68$, $d_{20^\circ} = 3.53$. Color green containing ferrous iron replacing the calcium and ferric iron replacing aluminum, and hence grading into grossular (and E. G. = 3.53). Color greenish white to pale green, gray, smoky- and honey-yellow, if wine-colored brownish yellow, even more brown, or rose-red (rare); emerald-green from the presence of chromium. Often shows octahedral granules (Art. 441).

[illegible]

1. But green, red, black, and some brown garnets are not typical representatives of the color group of garnets, etc. belong to the group of garnets, etc. garnets, or Amethyst.

B. Pyrope. Previous garnet in part. *Magnesian-aluminous Garnet*. Formula: $3\text{MgO} \cdot \text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 = \text{magnesia } 44.8\%$, $\text{aluminum } 25.4\%$, $\text{magnesian } 29.8 = 100$. *Magnesian* predominates, but calcium and iron are also present, the original pyrope also contained chromium. G = 3.51. Color deep red to nearly black. Often perfectly transparent and then prized as a gem. The name comes from *pyropos, lit.* fire.

Rhodolite, of delicate shades of pink, rose red and purple brilliant by reflected light, comes in as a comparison to two partial pyrope and one of a rhodolite, from Mason Co., North Carolina.

(*C*) ALMANDINE Almandine Precious garnet in part Common garnet in part Iron aluminous Garnet Formula $(\text{FeO Al}_2) 3\text{SiO}_4 = \text{SiO}_2 36.2$, $\text{Al}_2\text{O}_3 20.5$, iron protoxide 43.3 = 100. Ferric iron replaces the aluminum to a greater or less extent. Magnesium also replaces the ferric iron, and thus it grades toward pyrope, if rhodolite above ($C_1 = 4.25$). Color fine deep red, transparent in precious garnet, brownish red translucent or sub-translucent, in common garnet, black. Part of common garnet belongs to *Andradite*.

The Alabandian character of Pliny was so evident because of and pointed at Alabanda. Hence the name alabandine or almandite, now in use.

Morelia, called variously *bandeite*, *antilocate*, and *reebke*, also from Junges, Lower

[illegible][illegible][illegible][illegible]

Black myxomas (inclusions) are found on the

Die in der Tabelle angegebenen Werte sind die Mittelwerte der Messungen der 10 Proben. Die Standardabweichung ist in der Spalte "Standardabweichung" angegeben. Die Werte in der Spalte "Standardabweichung" sind die Standardabweichung der Messungen der 10 Proben.

Arrived in Aust-Agder, Norway, from Philadelphia on Monday, August 10, 1903. The weather was very warm and the water was very calm.

By the United States, granted in favor of Maine a

Newborn, Windham

[illegible][illegible]

$\frac{1}{\sqrt{\pi}} \int_{-\infty}^{\infty} f(x) e^{-x^2} dx = \frac{1}{\sqrt{\pi}} \int_{-\infty}^{\infty} f(x) e^{-x^2} dx$

[illegible][illegible][illegible]

1. The first thing I did was to go to the bank and see what I could do about getting a loan. I had a good idea of what I needed, but I didn't know where to go. I went to the bank and talked to the manager. He was very helpful and gave me a lot of advice. I was able to get a loan for \$10,000. I was very happy about this. I was able to get the money I needed to start my business. I was able to get the money I needed to start my business. I was able to get the money I needed to start my business.

Vin A light red wine from the warm, sunny hills of the south of France. It has a pale olive-green color.

Use.—As a plant of great medicinal properties, gardeners are used as scrupulous gardeners. A. leaves that have been found to be very good for the stomach.

Schorschorfite $\text{Fe}_2(\text{SO}_4)_3 \cdot 6\text{H}_2\text{O}$ garnet (80) Fe-Ti 3.38 TiO₂. Parting
to a $\text{Fe}_2(\text{SO}_4)_3 \cdot 6\text{H}_2\text{O}$ garnet. Usually massive, black, waxy
lustrous. $\text{Fe} = 7.7\%$, $\text{Ti} = 8.61\%$.

14 to 20. 16 small masses in 10 cephalopods and 1 rock is from Magnet Cove, near He

Spring, Garland Co., Arkansas. In masses of considerable size in a nephelite-syenite from the Ice River, a tributary of the Beaverfoot near Kicking Horse Pass, British Columbia.

Chrysolite Group. R_2SiO_4 Orthorhombic

| | | mm''' | hk' | | a | b | c |
|---------------|-----------------------|------------------------------|------------------------|--|--------|-----|--------|
| | | $110 \wedge \bar{1}\bar{1}0$ | $011 \wedge 0\bar{1}1$ | | | | |
| Monticellite | $CaMgSiO_4$ | $46^\circ 54'$ | $60^\circ 52'$ | | 0.4337 | 1 | 0.5758 |
| Glaucochroite | $CaMnSiO_4$ | $47^\circ 36'$ | $60^\circ 18'$ | | 0.441 | 1 | 0.591 |
| Forsterite | Mg_2SiO_4 | $49^\circ 51'$ | $60^\circ 43'$ | | 0.4618 | 1 | 0.5857 |
| Chrysolite | $(Mg, Fe)_2SiO_4$ | $49^\circ 57'$ | $60^\circ 47'$ | | 0.4656 | 1 | 0.5865 |
| Hortonolite | $(Fe, Mg, Mn)_2SiO_4$ | | | | | | |
| Fayalite | Fe_2SiO_4 | $40^\circ 15'$ | $60^\circ 10'$ | | 0.4584 | 1 | 0.5703 |
| Knoebelite | $(Fe, Mn)_2SiO_4$ | | | | | | |
| Tephroite | Mn_2SiO_4 | $40^\circ 24'$ | $61^\circ 25'$ | | 0.4600 | 1 | 0.5930 |
| Larsenite | $PbZnSiO_4$ | | | | 0.4319 | 1 | 0.5324 |

The **CHRYSOLITE GROUP** includes a series of orthosilicates of magnesium, calcium, iron and manganese. They all crystallize in the orthorhombic system with but little variation in axial ratio. The prismatic angle is about 50° , and that of the most brachydome about 60° , corresponding to the latter three-fold twins are observed. The type species is chrysolite (or olivine), which contains both magnesium and iron in varying proportions and is hence intermediate between the comparatively rare magnesium and iron silicates. X-ray study of the atomic structure shows that the SiO_4 groups are in dependence of each other, that the magnesium atoms lie between irregular groups of non-oxygen atoms and are of two kinds. In monticellite one set of magnesium atoms is replaced by calcium atoms. The oxygen atoms lie nearly in the positions required in a hexagonal close-packed structure.

In form the species of the Chrysolite Group, R_2SiO_4 , are closely related in nature to chondrodylite, $Be_3Al_2Si_6O_{20}$, and monazite and closely to the species of the Diaspore Group, H_2SiO_4 , etc. There is also an interesting relation between the chrysolites and the humates (see p. 628).

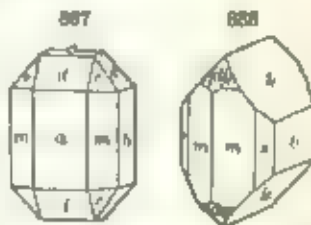
CHRYSOLITE. Olivine. Peridot.

Orthorhombic. Axes $a \ b \ c = 0.46576 \ 1 \ 0.5865$

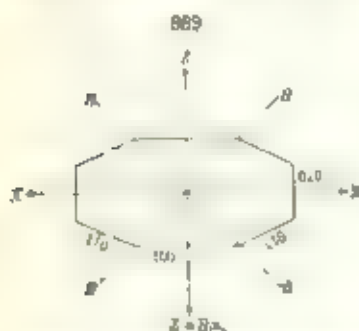
| | |
|-------|---------------------------------------------|
| mm | $110 \wedge \bar{1}\bar{1}0 = 46^\circ 57'$ |
| ss' | $120 \wedge \bar{1}20 = 94^\circ 4'$ |
| sd' | $101 \wedge 101 = 103^\circ 6'$ |
| hk' | $021 \wedge 0\bar{2}\bar{1} = 93^\circ 8'$ |
| rr | $111 \wedge \bar{1}\bar{1}1 = 40^\circ 5'$ |
| g' | $121 \wedge \bar{1}21 = 72^\circ 13'$ |

Twins rare. tw. $\{h(011)\}$ with angle between basal planes of the two individuals $\approx 60^\circ$; 47° , penetration-twins, sometimes repeated. tw. $\{h(012)\}$ the vertical axes crossing at an angle of about 30° . Crystals often flattened $\parallel a(100)$ or $b(010)$ less commonly elongated $\parallel c$ axis. Massive, compact, or granular in embedded grains.

Cleavage $\parallel b(010)$ rather distinct, $a(100)$ less so. Fracture conchoidal. Brittle. $H = 6.5-7$. $G = 3.27-3.37$, increasing with the amount of iron, 3.57 for hyaloseridite (30 per cent FeO). Luster vitreous. Color green -



commonly olive-green, sometimes brownish, grayish red, grayish green, becoming yellowish brown or red by oxidation of the iron. Streak usually uncolored, rarely yellowish. Transparent to translucent. Optically +. Ax



pl \perp (001), $Z \perp a(100)$. Dispersion $\rho < v$, weak. Axial angle large. $2V$ increases with rise in percentage of FeO, at about 13 percent FeO the axial angle becomes 60° , and with a further increase in FeO content the sign becomes -. Indices variable, increasing with change in percentages of FeO, commonly $\alpha = 1.635-1.656$, $\rho = 1.65-1.67$, $\gamma = 1.67-1.69$.

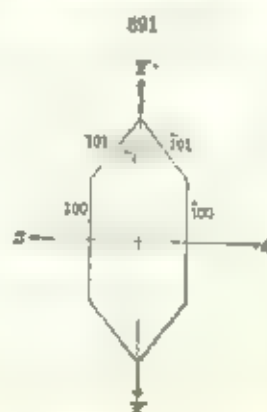
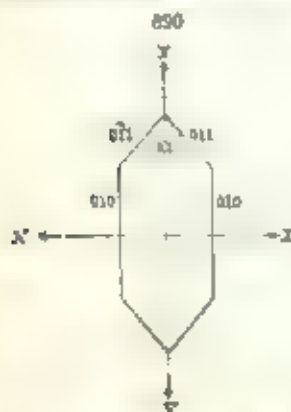
Var. occurs. Of a pale yellowish green color, at a depth of $0.2-3.14(1.56)$ cm. It is a very poor mineral as large as a turkey's egg, and is much smaller than a g. It is a bright green color for jewelry, but the exact locality is not known.

Common Occurrence. Dark yellowish green to black or reddish-green. $1.7-3.20(3.40)$ cm. It is a very poor mineral as large as a turkey's egg, and is much smaller than a g. It is a bright green color for jewelry, but the exact locality is not known.

Comp. $(Mg, Fe, Ni, Co)_2Si_2O_6$ or $2(Mg, Fe, Ni, Co)_2Si_2O_6$. The ratio of Mg to Fe varies widely, from 1.12 to 1.4, and to 2.1 in some cases, and hence passing from ferromagnesian on the one side to fayalitic on the other. No sharp line can be drawn on either side. The mineral is sometimes present in paying amounts, and is found in minute quantities.

Pyrr. etc. - It is a very poor mineral as large as a turkey's egg, and is much smaller than a g. It is a bright green color for jewelry, but the exact locality is not known.

Opt. - It is a very poor mineral as large as a turkey's egg, and is much smaller than a g. It is a bright green color for jewelry, but the exact locality is not known.



Micro. - It is a very poor mineral as large as a turkey's egg, and is much smaller than a g. It is a bright green color for jewelry, but the exact locality is not known.

limestone at Rolan Worcester Co., Massachusetts, in masses which are often over an inch thick and rectangular in section.

Hornstone - Fe-Mg silicate. In rough dark-colored crystals or masses. G = 3.00. Usually in large, coarse-grained masses. Found in the iron mine of Monroe, Orange Co., New York. Iron Stone Hill, Cumberland, Maine, and Rhode Island. Also reported from the

[illegible]

Kashchite. $\text{Ca}_2\text{Mg}_2\text{Si}_2\text{O}_{10}$. Rarely in crystals with habit similar to those of chrysotile. $n_x = 1.5$, $n_y = 1.4$, $n_z = 1.3$. Birefringence $\delta = 0.2$. $2V = 90^\circ$. Cleavage {110} and {010} perfect. Fracture conchoidal. Color gray, greenish gray, brownish gray, black. Streak grayish black. Luster vitreous to submetallic. Hardness 4.5. Density 3.4. Occurs in the same metamorphic sequence as fayalite.

Tephroite. — Mr. A. also with zinc in the variety *zozopriste*. Rarely in an all crystals like those of chrome. $\text{H} = 4$, $G = 4.1$. Color weak red to olive-gray. Streak gray. $Ax \mu = 0.9$. $A - B$ axis = $1.773 = 1.807 = 1.2A$. $2V = 6W$. Z found at Sterling Hill and Franklin Furnace, Sussex Co., New Jersey. A few very hard, specimens, at Persberg near Farsweg and at Långbanstjärnan. In former at Åkersviken Hallgrönsfjället. Pure tephroite from Långbanstjärnan is a variety intermediate between *forsterite* and *tremolite*.

Larvae. 1978-80. Orthochoelid ac. In slow but attracted primae, occasionally tabular (010). Prismatic cleavage good ($\angle = 540^\circ$). White and translucent. Acanthopore number 0. Optically Ax 1 = 001. $X = 9.4$ μ , $\lambda = 1.02$, $\mu = 1.00$, $\mu = 1.00$. $2\lambda =$ about 80° . I system, $\rho > \kappa$. Four lat traces in λ axis c. New Jersey in volcanic association with a diorite, hornfelsite, micaceous, schistose, sandstone, pegmatite, metabasite, etc.

Calcium-ferrosilite. $\text{Ph} = 4.700$, $\text{Ph} \text{ Cr} = \text{about } 1$. Massive. Indistinct cleavage, $\alpha = 1.131$. White, opaque. $n_{\text{parallel}} = 1.700$, $n_{\text{perpendicular}} = 1.709$. Another var. $\text{ph} = 4.40$, $\alpha = 1.700$, $\beta = 1.700$, $\gamma = 1.700$. Found in the same occurrence as calcicite at Franklin, Sussex Co., New Jersey.

Alleganyite.— $\text{MoO}_3 \cdot 2\text{SiO}_2$. Orthorhombic. Lustrous twinning shown in thin section in irregular grains. $11 \times 5.5 \times 4.0$. Color iridescent grayish pink. Density $d = 4.125$, $\rho = 4.180$, $\gamma = 4.179$. $2V = 72^\circ$. $\alpha > \gamma$. Form: a a vein with other minerals in a matrix of quartzite, chondritic magnesian siliceous calcite, tephroite, galuazite, etc. near the 1 km. Allegany Co., South America.

34 large Placochone λ = pure green yellow λ = pure green λ = pure green λ = pure green
From a rock of pure green λ = pure green λ = pure green λ = pure green λ = pure green

Larvae (Cassid.) Monophaga to grass and in parts have been taken as a pest.
Tale shows polytrophic feeding habits. (H) (Lange). (L) (Jennings). (S) Gray
Optically + 3 moderately large $\alpha = 170^\circ$, $d = 1.3$, $\gamma = 1.70$. Easy to trans-
form by heating or shock to another π -structure previously identified with the article in
 $\gamma = 48^\circ$. (Occurs in a host-parasite cycle at Searsville, near Larue, Co. A., Ia., pro-
liferated associated with spores of an unknown fungus and a species.

Merwinite $\text{Ca}_2\text{Al}_2\text{Si}_2\text{O}_{10} \cdot \text{Mg}(\text{OH})_2$. In grains, showing two axes of polyaxial stress twisting. $\text{Ca}:\text{Al}:\text{Si} = 1:1:1$. $\text{Cl} = 1.150$ 1 cleavage to pale green. Numerous luster. Transparency $\alpha = 1.704$, $\beta = 1.711$, $\gamma = 1.715$. $2V = 46^\circ$. Diaphane α to β to γ . $Z = 1$ (010). Δ Δ axes = 3μ . Absorption to moderate concordance with greenish grayrite and mont-sericite in the contact metamorphic zone at 1 cm depth, near Elvertite, Ca borate. Also noted with quartz and larnite at about 11 d, c-o-Antenn, Ireland area at Veladero, Dismal, Mexico.

[illegible]

Phenacite Group. R_2SiO_4 Tri-rhombohedral

| | | π' | c |
|-----------|-------------------|----------------|--------|
| Willemite | Zn_2SiO_4 | $64^\circ 30'$ | 0.6775 |
| Troostite | $(Zn, Mn)_2SiO_4$ | | |
| Phenacite | Be_2SiO_4 | $63^\circ 24'$ | 0.6611 |

The PHENACITE GROUP includes the above orthosilicates of zinc (manganese and beryllium). Both belong to the tri-rhombohedral class of the trigonal division of the hexagonal system, and have nearly the same rhombohedral angle. X-ray study of phenacite and willemite shows a more complicated atomic structure than with the minerals of the chrysote group. There are six molecules in the unit rhombohedral cell. The silicon and beryllium (or zinc) atoms are each surrounded by a tetrahedral group of oxygen atoms. Each oxygen atom is linked to one silicon and two beryllium (or zinc) atoms which lie nearly at the points of an equilateral triangle. The rare species trimenite, Mn_3SiO_8 , Be_3SiO_8 , which is pseudo-hexagonal (monoclinic) is perhaps to be regarded as connecting this group with the preceding Chrysote Group.

Diopside is probably related to the Phenacite Group with a similar structure. It also shows close crystallographic relations to the members of the Friedelite Group.

| Diopside | H_2CaSiO_4 Tri-rhombohedral | π' | c |
|----------|-------------------------------|---------------|--------|
| | | $54^\circ 5'$ | 0.5324 |

Friedelite Group

| | | | |
|-----------------|-----------------------------------------------------------------------|----------------|--------|
| Friedelite | $6MnO \cdot 2Mn \cdot OH \cdot Cl \cdot 6SiO_3 \cdot 3H_2O$ | | |
| | Rhombohedral | $50^\circ 17'$ | 0.5624 |
| Pyrosomalite | $6Fe, Mn \cdot 4(2Fe, Mn \cdot OH \cdot Cl \cdot 6SiO_3 \cdot 3H_2O)$ | | |
| | Rhombohedral | $53^\circ 40'$ | 0.5308 |
| Schafferite | $6MnO \cdot Mn_2(OH)_4As_2O_5 \cdot 6SiO_3 \cdot 3H_2O$ | | |
| Molybdophyllite | $4Mg, PbO \cdot 4Mg, Pb \cdot OH \cdot 4SiO_3 \cdot B_2O_3$ | | |
| | Rhombohedral | | 0.540 |

Various types of formulas have been assumed to the minerals of the Friedelite Group but the exact relations still seem uncertain. They show crystallographic and structural similarities. From the results of X-ray study on pyrosomalite it has been concluded that the formula should be written $3(Mn, Fe \cdot OH \cdot Cl \cdot Mn, Fe \cdot Si_2O_6)_2$. This, however, could be written similar to the formula given above and would differ only in having $4H_2O$ instead of $3H_2O$. If such molecules are present in the structural unit cell. It has been suggested that the species hemimite, dixenite, megovernite, hemitechite, parsettenite and errite may also be related to this group.

WILLEMITE.

Tri-rhombohedral. Axis $c = 0.6775$, $\pi' = 10\bar{1}1) \wedge \bar{1}101 = 64^\circ 30'$, $\pi' = 0112) \wedge (1012) = 36^\circ 47'$.

In hexagonal prisms, sometimes long and slender again short and stout; rarely showing subordinate faces distributed according to the phenacite type. Also massive and in disseminated grains fibrous.

Cleavage $\{100\}$ easy, Morcanet, difficult. New Jersey, a $11\bar{2}0$ easy,

Color blackish green to pale over brown or gray. Optically $\omega = 1.68$, $\epsilon = 1.64$. From the iron mines of Norrtärna, Västmanland and at Dannemora, in Upsala, Sweden.

PARMETTANITE. $2\text{MnO} \cdot 4\text{SiO}_2 \cdot 3\text{H}_2\text{O}$. Massive somewhat in acicular. $d = 2.60$. Decomposed by HCl with separation of silica. Insoluble with antimony. Color unaltered. Uniaxial, $\omega = 1.574$, $\epsilon = 1.56$. Found in manganese deposits at Parmettan, 4 p. Val d'Ery (Gnarus, Switzerland). A name supposed to differ in the amount of water present, or string associated with parmettane, and probably identical with it, has been named *erite*.

TANZENITE. $2\text{CaO} \cdot 4\text{Al}_2\text{O}_3 \cdot 3\text{MnO} \cdot 4\text{SiO}_2$. Good prismatic cleavage. Columnar structure. Color yellow to orange-red. Biaxial, $2V = 62^\circ$, $\omega = 1.63$, $\epsilon = 1.70$, $\gamma = 1.704$. $G = 3.70$. Occurs in veins with quartz in the manganese deposits at Tanzen, Val d'Ery (Gnarus, Switzerland).

Schallerite. $6\text{Al}_2\text{O}_3 \cdot \text{MgO} \cdot 2\text{H}_2\text{O} \cdot 4\text{SiO}_2 \cdot 6\text{SO}_3 \cdot 3\text{H}_2\text{O}$. Probably hexagonal. Massive. Basal cleavage. $H = 4.5$, $G = 3.37$. Dimeric, diaphanous. Light brown color. Vitraceous to waxy luster. Uniaxial, $\omega = 1.44$, $\epsilon = 1.67$. Occurs in veins in the ore body at Franklin, New Jersey. An iron-rich variety from the same locality has been called *ferroschallerite*.

Molybdophyllite. $(\text{Fe}, \text{Mg})_2\text{O} \cdot 4\text{SiO}_2$ (see also p. 601). Hexagonal, rhombohedral. In argillaceous masses with perfect basal cleavage. $H = 3.4$, $G = 4.7$. Dimeric, diaphanous. Colorless to pale green. Optically $\omega = 1.815$, $\epsilon = 1.791$. Occurs at Långgrändhyttan, Vermland, Sweden.

Scapolite Group. Tetragonal-tripyramidal

| | | | |
|------------------|--------------|--------------------------|--------------|
| Meionite | $c = 0.4393$ | Mizzonite, Dipyre | $c = 0.4424$ |
| Wernarite | $c = 0.4384$ | Marialite | $c = 0.4417$ |

The species of the SCAPOLITE GROUP crystallize in the pyramidal class of the tetragonal system with nearly the same axial ratio. They are white or grayish white in color except when impure, and then rarely of dark color. Hardness = 5.65. $G = 2.528$. In composition they are essentially silicates of aluminum with calcium and sodium in varying amounts, radicals involving Cl, OH, CO₂, or SO₄ are also present in small amounts.

The scapolites are analogous to the feldspars in that they form a series with a gradual variation in composition, the amount of silica increasing with the increase of the alkali, soda, being 40 per cent in meionite and 64 per cent in marialite. A corresponding increase is observed also in the amount of chlorine, etc. present. Furthermore there is also a gradual change in specific gravity, in the value of ω , and in resistance to acids, from the easily decomposed meionite, with $G = 2.72$, to marialite, which is only slightly attacked and has $G = 2.63$. The variation in composition may be explained by the isomorphous mixtures of various molecules, the two most important being,

| | | |
|------------------|-----------------------------------------------------------|-----------|
| Meionite | $\text{CaCO}_3 \cdot 3\text{CaAl}_2\text{Si}_2\text{O}_8$ | Me |
| Marialite | $\text{NaCl} \cdot 3\text{NaAlSi}_3\text{O}_8$ | Ma |

Other molecules, which are present at times in important amounts have been assumed to be $\frac{1}{2}(\text{CaCO}_3 \cdot 3\text{NaAlSi}_3\text{O}_8)$, $\frac{1}{2}(\text{H}_2\text{O} \cdot 3\text{NaAlSi}_3\text{O}_8)$, $\text{Na}_2\text{SO}_4 \cdot 3\text{NaAlSi}_3\text{O}_8$, $\text{Na}_2\text{HPO}_4 \cdot 3\text{NaAlSi}_3\text{O}_8$, $\text{CaSO}_4 \cdot 3\text{CaAl}_2\text{Si}_2\text{O}_8$, *intermediate*.

The composition therefore equals three plagioclase feldspar molecules (albite, anorthite, and probably carnegieite) plus one molecule of a salt which consists of a carbonate sulphate, or chloride. It has also been suggested that in the case of the molecules containing the sodium sulphate or carbonate radicals, these are present in one-half the amount given above, namely as $\frac{1}{2}(\text{Na}_2\text{CO}_3 \cdot 3\text{NaAlSi}_3\text{O}_8)$ and $\frac{1}{2}(\text{Na}_2\text{SO}_4 \cdot 3\text{NaAlSi}_3\text{O}_8)$.

A number of variety names have been applied to the scapolites, the

significance of which is often in doubt. Washell has proposed the following classification based upon the relative proportions of the two molecules, Me and Ma.

| | |
|----------------------|----------------------------------------|
| Mariakite to include | $Ma_{100}Me_0$ to $Ma_{50}Me_{50}$ |
| Dipyre | " $Ma_{50}Me_{50}$ to $Ma_{60}Me_{40}$ |
| Mazzonite | " $Ma_{60}Me_{40}$ to $Ma_{70}Me_{30}$ |
| Meionite | " $Ma_{70}Me_{30}$ to Ma_0Me_{100} |

Much the same classification is used here, except that dipyre is used as a synonym for mazzonite and the central portion of the series which is the rarest common in occurrence is given the name wernerite.

The tetragonal species melilitite and gehlenite are near the Scapolites in angle. The more common vesuvianite is also related.

MEIONITE.

Tetragonal. Axis $c = 0.439$. In prismatic crystals (Fig. 219, p. 102), either clear and glassy or milky white; also in crystalline grains and massive. Cleavage 010 rather perfect, 0110 somewhat less so. Fracture conchoidal. Brittle. $H = 5.5-6$. $G = 2.70-2.74$. Luster vitreous. Colorless to white. Transparent to translucent, often cracked within. Optically $\omega = 1.58-1.60$, $\epsilon = 1.55-1.56$.

Comp. $CaCO_3.3CaAl_2Si_2O_8$.

The meionite molecule, $NaCa_3Al_3Si_3O_{14}$, may occur in varying amounts up to 20 per cent.

Obs. Occurs in small crystals in gneisses, usually in light-colored rocks. Mt. Soudan, Vesuvius. Also in igneous masses, the Linacher See, Rhone and Carthage. A variety is an opaque bluish-green from the Lake Titicaca group, which is like meionite except for a small cleavage has been called, or *unimorphite*.

WERNERITE. Common Scapolite.

Tetragonal-pyramidal. Axis $c = 0.4384$.

Crystals pyramidal, usually coarse with uneven faces and often large. The asymmetry of the pyramidal class sometimes shown in the development of the faces 011 and $0\bar{1}1$. Also massive, granular or with a faint fibrous appearance when compact.

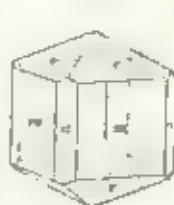
| | |
|------------|--------------------------------------|
| ω | $10^\circ \wedge 011 = 61^\circ 50'$ |
| ϵ | $31^\circ \wedge 11 = 35^\circ 15'$ |
| m | $1^\circ \wedge 11 = 54^\circ 2'$ |
| ϵ | $011 \wedge 311 = 20^\circ 30'$ |

Cleavage 010 and 0110 rather distinct but interrupted. Fracture subconchoidal. Brittle. $H = 5-6$. $G = 2.66-2.74$. Luster vitreous to poorly externally inclining to resinous, cleavage and cross-fracture surface vitreous. Color white, gray, bluish greenish, and reddish, usually light or pink uncolored. Transparent to faintly subtranslucent. Optically $\omega = 1.56-1.58$, $\epsilon = 1.54-1.55$.

Comp. Intermediate between meionite and mariakite and corresponding to a molecular composition of these in ratios from $Me_{50}Ma_{50}$ to $Me_{100}Ma_{00}$.

302

303



The silica varies from 46 to 54 per cent, and as its amount increases the soda and chlorine also increase.

Per. etc. B B fuses easily with int. interference to a white field by glass giving a strong blue color. It is a very hard mineral, and is not easily scratched by iron pyrites. It is a very hard mineral, and is not easily scratched by iron pyrites. It is a very hard mineral, and is not easily scratched by iron pyrites.

Micro. In thin sections it is a colorless, transparent mineral, and is not easily scratched by iron pyrites. It is a very hard mineral, and is not easily scratched by iron pyrites. It is a very hard mineral, and is not easily scratched by iron pyrites.

Obs. It is a very hard mineral, and is not easily scratched by iron pyrites. It is a very hard mineral, and is not easily scratched by iron pyrites. It is a very hard mineral, and is not easily scratched by iron pyrites. It is a very hard mineral, and is not easily scratched by iron pyrites.

Paragenesis. It is a very hard mineral, and is not easily scratched by iron pyrites. It is a very hard mineral, and is not easily scratched by iron pyrites. It is a very hard mineral, and is not easily scratched by iron pyrites. It is a very hard mineral, and is not easily scratched by iron pyrites.

Locality. It is a very hard mineral, and is not easily scratched by iron pyrites. It is a very hard mineral, and is not easily scratched by iron pyrites. It is a very hard mineral, and is not easily scratched by iron pyrites. It is a very hard mineral, and is not easily scratched by iron pyrites.

Properties. It is a very hard mineral, and is not easily scratched by iron pyrites. It is a very hard mineral, and is not easily scratched by iron pyrites. It is a very hard mineral, and is not easily scratched by iron pyrites. It is a very hard mineral, and is not easily scratched by iron pyrites.

Micro. It is a very hard mineral, and is not easily scratched by iron pyrites. It is a very hard mineral, and is not easily scratched by iron pyrites. It is a very hard mineral, and is not easily scratched by iron pyrites. It is a very hard mineral, and is not easily scratched by iron pyrites.

Crystallography. It is a very hard mineral, and is not easily scratched by iron pyrites. It is a very hard mineral, and is not easily scratched by iron pyrites. It is a very hard mineral, and is not easily scratched by iron pyrites. It is a very hard mineral, and is not easily scratched by iron pyrites.

Chemical analysis. It is a very hard mineral, and is not easily scratched by iron pyrites. It is a very hard mineral, and is not easily scratched by iron pyrites. It is a very hard mineral, and is not easily scratched by iron pyrites. It is a very hard mineral, and is not easily scratched by iron pyrites.

Synthetic. It is a very hard mineral, and is not easily scratched by iron pyrites. It is a very hard mineral, and is not easily scratched by iron pyrites. It is a very hard mineral, and is not easily scratched by iron pyrites. It is a very hard mineral, and is not easily scratched by iron pyrites.

MELNITE

Intergrowth. Axis $c = 0.4548$. Usually in short square prisms or octagons (rarely in thin plates), also in irregular masses.

Fracture. Conchoidal, distinct, or irregular. Fracture conchoidal to uneven. Hardness $H = 5$. $G = 29.310$. Luster vitreous, meaning it

various. Color white, pale yellow, greenish, reddish, brown. Pleochroism distinct in yellow varieties. Sometimes exhibit optical anomalies. Optical characters vary with composition. Usually transparent, but + for akermanite end of series. Indices for the chief component molecules, gehlenite, $\omega = 1.87$, $\epsilon = 1.66$; akermanite, $\omega = 1.63$, $\epsilon = 1.64$.

Comp. The composition is complex but can usually be expressed as varying isomorphous mixtures of two molecules, that of gehlenite, $\text{Ca}_2\text{Al}_2\text{Si}_2\text{O}_7$, and that of akermanite $\text{Ca}_2\text{MgSi}_2\text{O}_7$. In addition the following hypothetical molecules have been assumed by various writers to be present in minor amounts: soda-melinite, $\text{Na}_2\text{Si}_2\text{O}_7$; sub-melinite, CaSi_2O_7 ; calcium-akermanite, $\text{Ca}_3\text{Si}_2\text{O}_7$; iron-akermanite, $\text{Ca}_2\text{FeSi}_2\text{O}_7$; or a gehlenite, $\text{Ca}_2\text{Si}_2\text{O}_7$.

Acid. Melite has been formed artificially by fusing together its constituent oxides. This combination has also been prepared in various artificial glasses.

Pyx. etc. If B fuses at 3 to a very hard or greenish glass. With the fluxes reacts for amorphous to a transparent and colorless glass, and then gradually to a glass with evaporation.

Micro. Looking through the sections try to moderate reflection, very low interference colors, showing that the structure is of the type of the base, and the extinction is at right angles to the base. The base is a very common type of structure, and is found in the base of the base, and is penetrating the crystal from the basal plane toward the base, and is of the type of the base.

Obs. Melite is a very common mineral in the base of the base, and is of the type of the base. It is a very common mineral in the base of the base, and is of the type of the base. It is a very common mineral in the base of the base, and is of the type of the base.

The base of the base is a very common mineral in the base of the base, and is of the type of the base. It is a very common mineral in the base of the base, and is of the type of the base. It is a very common mineral in the base of the base, and is of the type of the base.

Melite is a very common mineral in the base of the base, and is of the type of the base. It is a very common mineral in the base of the base, and is of the type of the base. It is a very common mineral in the base of the base, and is of the type of the base.

Gehlenite is a very common mineral in the base of the base, and is of the type of the base. It is a very common mineral in the base of the base, and is of the type of the base. It is a very common mineral in the base of the base, and is of the type of the base.

Akermanite $\text{Ca}_2\text{MgSi}_2\text{O}_7$. Tetragonal. Isomorphous with gehlenite in solidite, when new. Found only in certain cases.

Hardyanite $\text{Ca}_2\text{Zn}_2\text{Si}_2\text{O}_7$. Tetragonal. A member of the Melite Group. In granular texture. Band cleavage and parting (100) and (110). $\text{H} = 4$, $\text{G} = 3.6$. Color white. Optically $\omega = 1.672$, $\epsilon = 1.661$. From Franklin Furnace Co., New Jersey.

Cebollite $\text{Hf}_2\text{Al}_2\text{Si}_2\text{O}_7$. Orthorhombic (?) Fibrous. $\text{H} = 6$, $\text{G} = 2.90$. Color white to greenish gray. In veins, 1/2 to 1/4 inch at 5. Soluble in acids. Found as an alteration product of melite near Cebolla Creek, Garfield Co., Colorado.

Diæ Characterized by its tetragonal form and easy fusibility. Resembles some known varieties of garnet, tourmaline, and epidote.

Micro Recognized in thin sections by its high refraction producing a very strong relief and its extremely low birefringence* and is generally in color, pleochroic, and unusual negative character. The latter on account of the low birefringence being like the diæ negative. The low birefringence, however, aids in distinguishing it from epidote, with which at times it may be confused.

Obs. Vesuvianite was first found among the ancient ejecta of Vesuvius and the doleritic dykes of Mt. Somma, whence its name. It occasionally occurs as a contact mineral formed from the alternation of igneous materials, then usually associated with grossularite-jadeite, diopside, wollastonite, also epidote, and serpentinite, chlorite, and other minerals and related rocks. It is never a constituent of igneous rocks.

It is found in the Achenbach, a tributary of the V. in Saxony (Saxony), Siberia, sometimes called *valite* or *valite* like the grossular garnet from the same region. This variety commonly known as *optically +*, and usually abnormally biaxial. At Achenbach near Hainichen in the Zittau district in the Erz Mts. For a distance northwest of Eger a fine blackish-brownish variety occurs in Hainichen at Opatowitz and neighboring Lohrstadt and at Moravitz. In Siberia at Ust'-Kamenogorsk and at Tselberg and near Jortan in the Ural Mountains. In Italy vesuvianite occurs in Trestino on Cassiole southwest of Pavia, Val di Bormio at Madonna, Val di Fiemme in Piedmont on the M. Alp in the Ala Valley in transparent green or brown brilliant crystals also from Locana northwest of Turin. From Africa and elsewhere in the Atlas Mts., south of Rome. At Vesuvius it is light-brown to olive-green, and sometimes in highly modified crystals. In Switzerland at Zermatt, Valais. In Norway at Trondhjem, Aker Agder, *vesuvianite*, at Egg, near Christiansund in Vest-Agder, in the Fikre parish, Hordaland between Kongsberg and Drammen, in Telemark the variety *cyrtine*. From Finland on Lake Ladoga at Lappeen near Imphale and at Pitkanen. It is well-defined crystals from Kiara, Bungo Province, Japan. In Mexico from the states of More and Chihuahua.

In the United States vesuvianite occurs in Maine at Auburn, Androscoggin Co. at Sanford York Co. etc. In New York south of Albany, Orange Co. greenish and yellowish crystals. In New Jersey at Franklin, Sussex Co. the variety *cyrtine*. From Magnet Cove near Hot Springs, Garland Co. Arkansas. In California it occurs at Crestmore. It varies in color and the closely compact variety *chrysolite*, with an olive-green to a grass-green color from Sakayama, and *valite* etc. etc.

L. *valite* light brownish yellow crystals occur at Calumet Falls, Litchfield, Putnam Co. from Chappaqua Co. at Tarrytown in brownish red crystals, and at Wakefield green and bright yellow. It occurs in masses and in small crystals of a light pink color from Buck Lake, Michigan Co. (Michigan-terrestrial).

Chemistry. Essentially a silicate of calcium and aluminum. Tetragonal, prismatic cleavages (100) and (001). Color gray. Optically $n_x = 1.707$, $n_y = 1.698$, $n_z = 1.616$. Occurs in granites at Sidi Bou Slimane, Morocco. Originally described as *cyrtine*. Possibly identical with *vesuvianite*.

Zircon Group. ¹²RSO. Tetragonal

Zircon
Thorite

$ZrSiO_4$
 $ThSiO_4$

$n = 0.6404$
 $n = 0.6402$

This group includes the orthosilicates of zirconium and thorium, both alike in tetragonal crystallization, axial ratio, crystalline habit, and atomic structure.

These species are closely related to the members of the Rutile Group both as to crystal content in igneous structures. See further on p. 408.

* Frequently numerous, which, like vesuvianite, melilite and zirconite are doubly refracting but of extremely low birefringence and possibly when they are positive for one color but negative for another. do not show a gray color between crossed nicols but a numerous blue or lilac an intense hard blue which is quite distinct from the other sides of the color scale and is known as the "ultra blue."

ZIRCON.

Tetragonal. Axis $c = 0.84037$.

$$ap, 101 \wedge 011 = 44^\circ 50'$$

$$ap, 101 \wedge 101 = 65^\circ 16'$$

$$pp, 111 \wedge 111 = 56^\circ 40\frac{1}{2}'$$

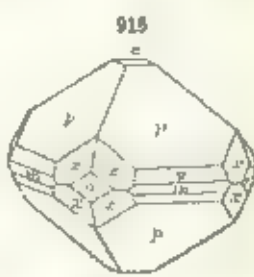
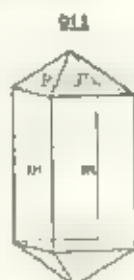
$$ap, 311 \wedge 311 = 83^\circ 9'$$

$$mp, 110 \wedge 111 = 47^\circ 50'$$

$$mp, 110 \wedge 311 = 20^\circ 12\frac{1}{2}'$$

$$ap, 311 \wedge 311 = 32^\circ 57'$$

$$ap, 100 \wedge 311 = 31^\circ 43'$$



Crystals

Twins: tw pl c 101), geniculated twins like rutile (Fig. 438, p. 188). Commonly in square prisms, sometimes pyramidal. Also in irregular forms and grains.

Cleavage: m {110} imperfect, p {111} less distinct. Fracture conchoidal. Brittle. $H = 7.5$, $G = 4.68-4.70$ most common but varying widely from 4.2 to 4.86. Luster adamantine. Colorless, pure yellowish, grayish, yellowish green, brownish yellow, reddish brown. Streak asch. red. Transparent to subtranslucent and opaque. Optically +. Birefringence high. $n_\omega = 1.923-1.960$, $n_\epsilon = 1.938-2.015$. Sometimes abnormally biaxial.

Dyscrith is the orange, reddish and brownish transparent kind, used for gems. Japanese kaolin gives it the orange or rusty colors of the red in allusion to the fact that while resembling the gemstone in color they are comparatively worthless. It sometimes has the name *zircon*. The mineral has been given only to zircon, a superficial and treatment in which the zircon is exposed to fumes derived from a mixture of ceric nitrate and potassium ferrocyanide. Gem stones from this material have been called *zirconite*.

Comp. $ZrSiO_4$ or $ZrO_2 \cdot SiO_2 =$ Silica 32.8, zirconia 67.2 = 100. A little iron (Fe_2O_3) is usually present.

Some varieties contain hafnium oxide up to 4 per cent. The rare earths occur in the variety *happanite* from Nagata, Iyo Province, Japan. *Oyamite* is a variety containing considerable phosphorus from Oyama, Iyo Province, Japan.

Thorstite. Alteration material of thortveitite occurring at Hyslop, Colorado, in minute quantities have been analyzed. It is a silicate of thorium. From chemical tests they appear to be an isomorphous mixture of thortveitite and thortveitite, with at least a trace of thorium. It is a silicate of thorium, with a trace of thorium. It is a silicate of thorium, with a trace of thorium. It is a silicate of thorium, with a trace of thorium.

Auerite. Like thortveitite, it is a silicate of thorium. It is a silicate of thorium, with a trace of thorium. It is a silicate of thorium, with a trace of thorium. It is a silicate of thorium, with a trace of thorium.

Danburite-Topaz Group. Orthorhombic $\text{R}^{2+}_2(\text{SiO}_3)_2$ or $(\text{R}^{2+})_2(\text{SiO}_3)_2$

| | | |
|------------|--------------------------------------------------------|--------------------------------------|
| Danburite | $\text{CaB}_2(\text{SiO}_3)_2$ | $a \ b \ c = 0.5444 \ 1 \ 0.4807$ |
| Topaz | $\text{Al}_2\text{F}_2(\text{OH})_2(\text{AlSiO}_3)_2$ | $a \ b \ c = 0.5285 \ 1 \ 0.4770$ |
| Andalusite | $(\text{AlO})_2(\text{AlSiO}_3)_2$ | $2b \ a \ 3c = 0.5470 \ 1 \ 0.4749$ |
| | | or $a : b : c = 0.9861 : 1 : 0.7025$ |

| | | |
|-------------|---------------------------|---------------------------------------------------------------------------------------------------|
| Sillimanite | Al_2SiO_5 | Orthorhombic $a \ b \ c = 1.970 \ 1 \ 0.70$ |
| Kyanite | Al_2SiO_5 | Triclinic |
| | | $a : b : c = 0.8994 \ 1.07000, \alpha = 90^\circ 51', \mu = 101^\circ 2', \gamma = 105^\circ 44'$ |

Andalusite, Sillimanite, and Kyanite constitute trimorphic forms of Al_2SiO_5 . The X-ray study of these minerals shows certain close relations in their atomic structures. The unit cells of all three have nearly the same dimensions, which agree in relative values with the axial ratios given above. Parallel to the vertical axes there are chains of aluminum atoms lying in the centers of groups of six oxygen atoms, each group sharing two oxygen atoms with each of the groups above and below. These aluminum-oxygen chains have therefore the composition of AlO_2 . The positions of these chains are practically identical in andalusite and sillimanite and nearly the same in the case of kyanite. These vertical chains are linked together by the remaining Al, Si, and O atoms, and the variations in the structure of the three minerals are due to the different ways in which this linking takes place. In all cases the silicon lies between four oxygen atoms, giving in the structure independent SiO_4 groups. The remaining non-chain atoms are supposed to be between six oxygen atoms in kyanite, between five in andalusite, and four in sillimanite.

DANBURITE.

Orthorhombic. Axes $a \ b \ c = 0.5444 \ 1 \ 0.4807$

917

mm. $11.1 \times 10 \times 8.5$ $2d \ 191 \times 101 = 2^\circ 53'$
 $100 \times 20 = 95^\circ$ $2d \ 101 \times 101 = 12^\circ 50'$



Habit prismatic, resembling topaz. Also in interstitial embedded crystals and disseminated masses. X-ray study of the atomic structure shows that each cell contains four molecules and that the axial ratio derived from these dimensions should be $1.09134 \ 0.8822$, or $1.001 \ 1.0903$. Each silicon atom is at the center of a group of four oxygen atoms, the other groups having one atom of oxygen between them. The rest of the structure is therefore built up of such groups having one atom of oxygen between them. The oxygen atoms form another tetrahedral group with one oxygen atom from each of three SiO_4 groups, and in the center of each group are the boron atoms.

The oxygen atoms form another tetrahedral group with one oxygen atom from each of three SiO_4 groups, and in the center of each group are the boron atoms.

Cleavage: $\alpha(001)$ very indistinct. Fracture uneven to subconchoidal. Brittle. $H = 7.7-25$ $G = 2.97-3.02$. Color pale wine-yellow to colorless, yellowish white, dark wine-yellow, yellowish brown. Luster vitreous to greasy, on crystal surfaces brilliant. Transparent to translucent. Streak white. Strong luster being easily for red, yellow, and green light but + for blue light. Ax pl. (001) ; $X = b$ axis. $2V = 85^\circ$ to 90° $\alpha = 1.630$, $\beta = 1.633$, $\gamma = 1.636$.

Comp. $\text{Ca}_2\text{B}_2\text{SiO}_7$ or $\text{CaO B}_2\text{O}_3 \cdot 2\text{SiO}_2 = \text{SiO}_2$ 48.8, boron trioxide 28.4, lime 22.8 = 100

Pyrr., etc. = B H fuses at 3.5 to a colorless glass, and imparts a green color to the O.F. (boron). Not decomposed by hydrochloric acid but effervesces at access of the solution to give the reaction of boron acid with amine paper. When previously ignited gemstones with hydrochloric acid phosphoresce a bright green or reddish light.

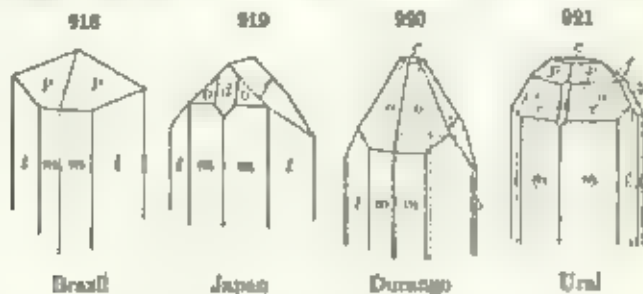
Obs. Occurs at Danbury, Fairfield Co., Connecticut, with microcline and oligoclase in dolomite. At Rensselaer, Lawrence Co., New York, in anorthite. On Pt. Palisade, the northern spur of Mt. Beacon, east of Lakemont, in Va. Mostly, Ural, now abundant in slender, fibrous crystals and elsewhere in Switzerland. In crystals from Oboro, B.ogo, Japan. In Madagascar at Mahorah on Mt. Bity, at Imah near Manna, south of Betafie district, and in large crystals at Sahasany, northeast of Andina.

Basal form. This doubtful species, occurring with blue cerussite in the Ural Mts., is by some authors classed with dactynite; composition $\text{Ca}_2\text{B}_2\text{SiO}_7$, like anorthite.

TOPAZ

Orthorhombic. Axes $a : b : c = 0.52854 : 1 : 0.47698$.

| | | |
|---------------------------------------------------|-----------------------------------------------|-----------------------------------------------------|
| m , $110 \wedge \bar{1}\bar{1}0 = 55^\circ 43'$ | mp , $041 \wedge 0\bar{4}1 = 124^\circ 41'$ | mn , $111 \wedge \bar{1}\bar{1}1 = 78^\circ 20'$ |
| p , $120 \wedge \bar{1}20 = 86^\circ 40'$ | cr , $001 \wedge 221 = 34^\circ 14'$ | mn'' , $111 \wedge \bar{1}\bar{1}1 = 39^\circ 0'$ |
| l , $201 \wedge \bar{2}01 = 127^\circ 1'$ | cu , $001 \wedge 111 = 45^\circ 35'$ | cr' , $221 \wedge \bar{2}21 = 108^\circ 7'$ |
| vk , $043 \wedge 0\bar{4}3 = 64^\circ 56'$ | co , $001 \wedge 221 = 63^\circ 53'$ | cr'' , $221 \wedge \bar{2}21 = 40^\circ 37'$ |
| f , $021 \wedge \bar{0}21 = 67^\circ 18'$ | | |



Crystals commonly prismatic, on 110 predominating, or $\bar{h}120$ and the form then a nearly square prism resembling andalusite. Faces in the prismatic zone often vertically striated, and often showing vicinal planes. Also firm, conchoidal, granular, coarse or fine. X-ray study of the atomic structure reveals the following facts: the SiO_4 groups are independent of each other, the aluminum atoms are linked to four oxygen atoms and two (F, OH) groups, each oxygen atom is linked to one silicon and two aluminum atoms, the (F, OH) groups are between two aluminum atoms, there are four molecules in the unit cell, the dimensions of which are relatively $a : b : c = 8.78$, and $b : a$.

Cleavage: $\alpha(001)$ highly perfect. Fracture subconchoidal to uneven. Brittle. $H = 8$ $G = 3.4-3.6$. Luster vitreous. Color straw-yellow, wine-yellow, white, grayish, greenish, bluish, reddish. Streak uncolored.

The name *topaz* is from *topazion*, an island in the Red Sea, as stated by Pliny. But the *topaz* of Pliny was not the true *topaz*, as it "yielded to the file." *Topaz* was included by Pliny and earlier writers, as well as by many later under the name *chrysoberyl*.
Use. As a gem stone.

ANDALUSITE.

Orthorhombic. Axes $a : b : c = 0.9861 : 1 : 0.70245$.

$$\begin{aligned} \text{mm}''' & 110 \wedge 1\bar{1}0 = 89^\circ 12' \\ w' & 011 \wedge 0\bar{1}1 = 70^\circ 10' \end{aligned}$$

Usually in coarse prismatic forms, the prisms nearly square in form. Massive, imperfectly columnar, sometimes radiated and granular. For a discussion of the atomic structure see p. 612.

Cleavage m (110) distinct, sometimes perfect (Brazil). a (100) less perfect, b (010) in traces. Fracture uneven, subconchoidal. Brinell $H = 7.5$. $G = 3.16-3.20$. Luster vitreous, often weak. Color whitish, rose-red, flesh-red, violet, pearl-gray, reddish brown, olive-green. Streak uncolored. Transparent to opaque, usually subtranslucent.

Pleochroism strong in some colored varieties. Absorption strong, $X > Y > Z$. Sections normal to an optic axis are isotropic or show the polarization brushes distinctly (p. 317). Optically - Ax pl. b (010). $Bx \perp c$ (001). $2V = 85^\circ$, $\alpha = 1.634$, $\beta = 1.639$, $\gamma = 1.643$. *Manganandalusite* or *viridula* (considered by some authors to be a distinct species) is optically +; $\lambda = a$ axis. $\alpha = 1.66$, $\beta = 1.67$, $\gamma = 1.69$. Dark green color and pleochroism yellow to green.

Var. *Chondulite* or *Made* is a variety in stout crystals having the axis a and a of a different color from the rest, owing to a regular arrangement of microscopic inclusions through the a -axis, and hence exhibiting a colored cross, or a tessellated appearance in a transverse section. Fig. 927 shows sections of a crystal. *Viridula* is a green variety containing some iron and manganese from near Darmstadt, Germany.

Comp. $Al_2SiO_5 = (AlO)AlSiO_3$, or $Al_2O_3 \cdot SiO_2 = \text{Silica } 36.8, \text{ alumina } 63.2 = 100$. Manganese is sometimes present, as in *manganandalusite* or *viridula*.

927



Andalusite when heated to $1400^\circ C$ changes to a mixture of *mullite*, $3Al_2O_3 \cdot 2SiO_2$, and silica.

Pyrr., etc. - B.B. infusible. With cobalt solution gives a blue color after ignition. Not decomposed by acid. Decomposed on fusion with caustic alkalis and alkaline carbonates.

Dist. Characterized by the nearly square prism, pleochroism, hardness, infusibility; reaction for alumina B.B.

Micro. Distinguished in thin sections by its high relief, low interference-colors, which are not easily shown through quartz, feldspar, hornblende, garnet, etc. Most of the crystals will from side to side rather than in prismatic cleavage as the corundum, and as about 15° from pyramids which have also greater lateral growth, and its characteristic arrangement of angular well-been crystals (Fig. 927). The pleochroism, when well showing as when present, strong and characteristic.

Obs. As a mineral it is not much used as a gemstone, but it has a fine and argillaceous or earthy appearance in combination with greenish minerals, and also serves to greenish, and as a color indicator in rocks, and with the aid of a microscope, it is a good indicator of the nature of the rock. It is a good indicator of the nature of the rock. It is a good indicator of the nature of the rock. It is a good indicator of the nature of the rock.

Loc. Nankovka in the Verkhovsk district, Transbaikalia, *chertovite* in the Tundra Mountains, north of Ekaterinburg, a large amount with kyanite in the Alps, near the town of Austria. At the base of the Alps, near the town of Austria, near the town of Austria. In the Alps, near the town of Austria, near the town of Austria. In the Alps, near the town of Austria, near the town of Austria.

Use. In the Alps, near the town of Austria, near the town of Austria. In the Alps, near the town of Austria, near the town of Austria. In the Alps, near the town of Austria, near the town of Austria. In the Alps, near the town of Austria, near the town of Austria.

Notes. From the Alps, near the town of Austria, near the town of Austria. In the Alps, near the town of Austria, near the town of Austria. In the Alps, near the town of Austria, near the town of Austria. In the Alps, near the town of Austria, near the town of Austria.

Use. When clear and transparent may serve as a gemstone. Also used in the manufacture of the porcelain of spark plugs.

SILLIMANITE. Fibrolite.

Orthorhombic. Axes $a : b : c = 0.970 : 1 : 0.70$ mm. $\angle 110^\circ \wedge 110^\circ = 88^\circ 15'$, $\angle 110^\circ \wedge 110^\circ = 100^\circ$. Pleochroism: greenish yellow, rounded. Commonly in long slender crystals not distinctly terminated, often in close parallel groups, passing into fibrous and even into massive forms, sometimes twinning. Pleochroism: greenish yellow, rounded.

Cleavage: b only, very perfect. Fracture uneven. $H = 6.7$. $G = 3.23-3.24$. Luster vitreous, approaching subadamantine. Color fair-brown, grayish brown, grayish white, grayish green, pale olive-green. Streak uncolored, transparent to translucent. Pleochroism: sometimes distinct. $\alpha = 1.638-1.650$, $\beta = 1.642-1.660$, $\gamma = 1.643-1.650$. Dispersion $\gamma > \alpha$. Axial angles and indices variable. $2V = 25^\circ$ (approx.) $\alpha = 1.638-1.650$, $\beta = 1.642-1.660$, $\gamma = 1.643-1.650$.

Comp. $\text{Al}_2\text{SiO}_5 = (\text{Al} + \text{Si})_2\text{O}_5$, like andalusite. Silica 36.8, alumina 63.2 = 100.

Andalusite is the most stable of the three polymorphs. But when heated to temperatures above 1400° changes to a mixture of Al_2SiO_5 , 2SiO_2 , and silica.

Pyr. None as andalusite.

Diff. Characterized by its fibrous or columnar form, perfect cleavage, pleochroism, and for the color.

Micro. In thin sections recognized by its form, usually with transverse fractures, parallel extinction; high refractive index.

Artif. It has been used for the manufacture of the gemstone, and for the manufacture of the gemstone.

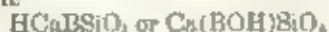
Obs. It has been found in the Alps, near the town of Austria, near the town of Austria. In the Alps, near the town of Austria, near the town of Austria. In the Alps, near the town of Austria, near the town of Austria. In the Alps, near the town of Austria, near the town of Austria.

Datolite Group. Monoclinic

Basic Orthosilicates. $\overline{H}R\overline{R}(SiO_4)_2$ or $\overline{R}_2\overline{R}_2(SiO_4)_2$. Oxygen ratio for $R : Si = 3 : 2$

$\overline{R} = (Ca, Be, Fe, \text{chiefly})$, $\overline{R} = \text{Boron, the yttrium and cerium metals, etc}$
 $a : b : c$

Datolite 0.6345 1 1.2657 $89^\circ 51'$



Hemidatite 0.6249 1 1.2624 $89^\circ 21'$



Eucase 0.6474 1 1.3330 $79^\circ 44'$



Gadolinite 0.6273 1 1.3215 $89^\circ 26\frac{1}{2}'$



The species of the DATOLITE GROUP are usually regarded as basic orthosilicates, the formulas being taken in the second form given above. They all crystallize in the monoclinic system, and all but eucase conform closely in axial ratio. X-ray study, however, shows close structural relationship between datolite and eucase.

DATOLITE

Monoclinic Axes $a : b : c = 0.6345 : 1 : 1.2657$, $\beta = 89^\circ 51\frac{1}{2}'$

$$mm, 110 \wedge 1\overline{1}0 = 104^\circ 47'$$

$$oa, 100 \wedge 001 = 59^\circ 51'$$

$$ax, 100 \wedge 101 = 45^\circ 0'$$

$$pv, 012 \wedge 0\overline{1}\overline{2} = 64^\circ 39'$$

$$m_2m_2, 011 \wedge 0\overline{1}\overline{1} = 103^\circ 25'$$

$$cm, 001 \wedge 111 = 66^\circ 57'$$

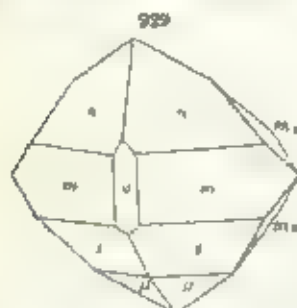
$$cm, 001 \wedge 110 = 81^\circ 53'$$

$$ca, 001 \wedge 112 = 49^\circ 49'$$

$$ab, 111 \wedge 1\overline{1}\overline{1} = 59^\circ 41'$$

$$a, 112 \wedge 1\overline{1}\overline{2} = 48^\circ 50'$$

Crystals varied in habit, usually short prismatic with either $m(110)$ or $m_2(011)$ predominating, sometimes tabular $\perp c(201)$; also of other types,

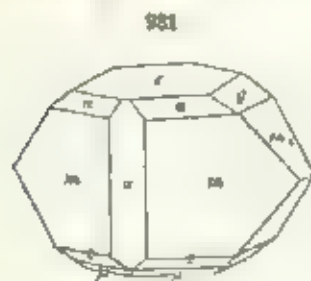


Bergan Hill

and often highly modified (Figs 929-932). Also botryoidal and globular, having a columnar structure, divergent and radiating; sometimes massive, granular to compact and cryptocrystalline.

Cleavage not observed. Fracture conchoidal to uneven. Brittle. $H = 5.5-5$, $G = 2.9-3.0$. Luster vitreous, rarely subresinous on a surface of fracture. Color white, sometimes grayish, pale green, yellow, red, or

amethystine, rarely dirty olive-green or honey-yellow. Streak white. Transparent to translucent; rarely opaque white. Optically — Ax pl || (010) and Z nearly c axis. $2V = 74^\circ$, $\alpha = 1.629$, $\beta = 1.654$, $\gamma = 1.670$.



Between Hill



Appendix

Var. — 1. Ordinary. In glassy crystals of varied habit, usually with a greenish tinge. The angles in the prismatic and clinodome zones vary but little, e.g., $110 \wedge 116 = 155^\circ 37'$ while $011 \wedge 011 = 60^\circ 37'$, etc. — *Chemical reaction.* Opaque, white, cream-colored, pink breaking with the surface of porcelain or Weymouth ware. From the Lake Superior region. *3. Paragonized. Hypocrite.* Reticulated columnar having a botryoidal surface, and containing more water than the crystals, but optically identical.

Comp. A basic orthosilicate of boron and calcium, empirically HCaBSiO_4 or $\text{H}_2\text{O} \cdot 20\text{H} \cdot \text{B}_2\text{O}_3 \cdot 2\text{SiO}_2$, this may be written $\text{Ca}(\text{BOH})_2\text{SiO}_4$ = Silica 37.6, boron trioxide 21.8, lime 35.0, water 5.6 = 100.

Py₂, etc. — In the closed tube gives off much water. B. B. fuses at 2 with intumescence to a clear glass coloring the Ag as light green. Combustion with hydrochloric acid.

Diff. Characterized by its glassy, greenish, octahedral crystals, may be white and green
Name: B.D.

Obs. Dolomite is found chiefly as a secondary mineral in veins and cavities in basic eruptive rocks, often associated with calcite, pyrrhotite and various sulfides. Sometimes associated with hematite, also in gneiss and as a replacement in igneous rocks. Sometimes in beds of marble. Found at Andriessberg in the U. S. A. in connection with veins of silver ore. In Italy from Treviso on the Sesia, Alps. Mont. Isère, also at Lago Tignes, northeast of Courmayeur. Graded in magnesian from sediment in gneiss at Passovio, Lago Maggiore. In France at Tignes near Mont Blanc, in serpentinite at Font-Saint-Jean. In Switzerland at the Apennines near Bellinzona in basic complex gneiss. In Spain from Ariza in Ariz-Aguz in a bed of magnetite, barite. From Rosebery, Montana, U. S. A.

In the United States not uncommon with the diabase of the Connecticut River valley as at West Hill, Hampton Co., Massachusetts, in connection with Hartford, etc. In large crystals at Hartford and from near Hartford at Mountain New Hampshire etc. In New Jersey in the trap rocks of Bergen Hill, Great Notch, Paterson, etc. In sporadic crystals and associated with various zeolites etc. In Michigan at Ishpeming etc. In compact opaque varieties associated with the trap rocks of the copper district of Keweenaw Co.,

Named from *hercynite*, the hercynite rock in the contact aureole of the *hercynite* zone.
 Homilita. — (Ca²⁺, Fe²⁺, Mn²⁺, Mg²⁺, Al³⁺, Fe³⁺, Ba) SiO₃. Very good cleavage, 010° angles near those of anorthite. H = 5. G = 3.8. Earthy, pale color, bases, lustrous brown. Optically +. Ax. pl. ± 010°. Z = 6 axis. T_{max} = 17.5. n_x = 1.25, n_y = 1.738. Altered material may be isotropic or anisotropic with variable optical properties. Found on stock and on islands in the Lacassagne River, near here. 5 mm.

Euclase - HfBeAs₂Si₂ or Be AlO(H₂Si₂). In prismatic crystals (lens-like, 0.010 mm). H = 7.5 (ρ = 3.65-3.10). Luster vitreous (translucent to pale green or blue). Chl only + Ax. pl. (010) 24 + 50° σ = 1.652, μ = 1.66, γ = 1.671. Found in the southern sector in the Orskan district of the southern Ural Mts., near the river Sam-

β . Monoclinic Section

| | | a, b, c | β |
|--------------|--------------------------------------------------------------------------------------------------------------|----------------|----------------|
| Clinozoisite | $C_{24}(Al_2OH)Al_3(SiO_3)_6$ | 1.583 1.1814 | $64^\circ 30'$ |
| Epidote | $\left\{ \begin{array}{l} Ca_{1.5}Al_2(OH)Al_3(SiO_3)_6 \\ Ca_{1.5}Fe_2(OH)Fe_3SiO_{11} \end{array} \right.$ | 1.5787 1.18036 | $64^\circ 37'$ |
| Piedmontite | $C_{24}Al_2(OH)Al_3Mn_3SiO_{11}$ | 1.8100 1.18326 | $64^\circ 30'$ |
| Allanite | $(Ca, Fe)_3(Al_2OH)(Al, Fe, Si)_3SiO_{11}$ | 1.5369 1.17691 | $64^\circ 59'$ |

The Epidote Group includes the above complex orthosilicates. The monoclinic species agree close in form to them; the orthorhombic species zoisite is also related in angle, its prismatic zone corresponding to the monoclinic orthorhombic, etc. Thus we have

| | | | |
|---------|-------------------------------------------------|---------|------------------------------------------------------|
| Zoisite | mm' $110 \wedge \bar{1}\bar{1}0 = 63^\circ 34'$ | Epidote | σ , $001 \wedge \bar{1}01 = 43^\circ 42'$ |
| | mm', $021 \wedge 0\bar{2}1 = 58^\circ 54'$ | | mm', $110 \wedge \bar{1}\bar{1}0 = 70^\circ 4'$ etc. |

X-ray studies of zoisite and epidote show close relationships between their atomic structures. The elementary cell of zoisite contains four molecules whereas that of epidote contains but two. The respective cells have the same dimensions practically identical with the third dimension in zoisite is twice the corresponding dimension in epidote. This leads to a crystal orientation of zoisite in which axis b as given above, becomes a , c becomes b , and a becomes c , so that the axial ratio equals 1.03429 : 0.6196 or 2.916 : 1.501. This last expression is practically that of epidote except that the value for a has been doubled.

ZOISITE.

Orthorhombic Axes $a : b : c = 0.6196 : 1 : 0.34295$

| | |
|--------------------------------------------------|--------------------------------------------------------|
| mm', $111 \wedge \bar{1}\bar{1}0 = 61^\circ 54'$ | β , $011 \wedge 0\bar{1}1 = 37^\circ 52'$ |
| ss', $101 \wedge \bar{1}01 = 57^\circ 36'$ | σ , $111 \wedge \bar{1}\bar{1}1 = 43^\circ 24'$ |

Crystals prismatic, deeply striated or furrowed vertically, and seldom distinctly terminated. Also massive, columnar to compact.

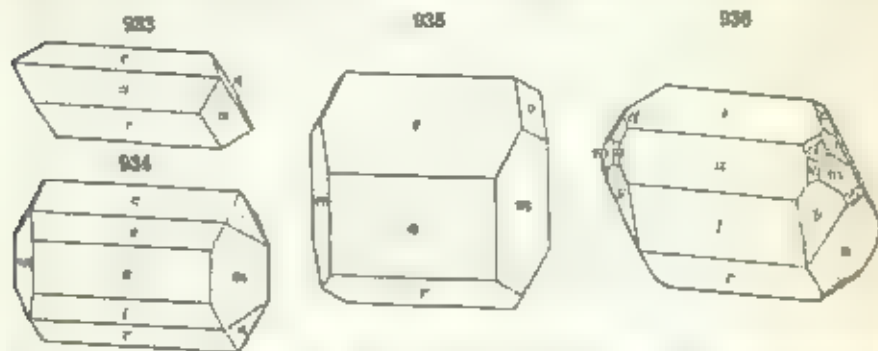
Cleavage $b(010)$ very perfect. Fracture uneven to subconchoidal. Brittle. $H = 6-6.5$. $G = 3.25-3.37$. Luster vitreous on the cleavage-face, $b(010)$, pearly. Color grayish white, gray, yellowish brown, greenish gray, apple-green, also peach-blossom-red to rose-red. Streak unaltered. Transparent to subtranslucent.

Isomorphism strong in pink varieties. Optically +. Ax. pl. usually $b(010)$, in iron-free zoisite, also $c(001)$, with about 6 per cent Fe_2O_3 . Bx. $a(100)$. Dispersion strong, $\rho < \epsilon$ iron-free, and $\rho > \epsilon$ (with 5 per cent Fe_2O_3). Axial angle variable even in the same crystal, increasing in value with increase in iron content. $2V$ varies widely from about 30° for varieties with little iron to 0° and then increasing again to about 60° with increase in iron content. $\alpha = 1.700$ $\beta = 1.703$ $\gamma = 1.706$.

Var. — 1. Ordinary + colors gray to white and brown, also green. Usually in constant prismatic or columnar forms, also in columnar aggregates. $G = 3.226-3.381$. Iron-free is a very pure zoisite. 2. Rose-red or Peach. Fe-rich monoclinic strong. 3. Compact, massive. Includes the essential part of most of the mineral material known as coesite (e.g., in aluminosilicates), which has arisen from the alteration of feldspar.

Comp. $Hf_{12}Al_6Si_6O_{18}$ or $4CaO \cdot 3Al_2O_3 \cdot 6SiO_2 \cdot H_2O$ = Silica 39.7 alumina 33.7, lime 24.6, water 2.0 = 100. The alumina is sometimes replaced

Pleochroism strong: vibrations $\parallel Z$ green, Y brown and strongly absorbed, X yellow. Absorption usually $Y > Z > X$; but sometimes $Z > Y > X$ in the variety of epidote common in rocks. Often exhibits idiophanous figures best in sections normal to an optic axis, but often to be observed in natural crystals (Sulzbach), especially if flattened. (See p. 317) Op-



tically — Ax pl. $h(101)$ $X \wedge c$ axis = $0^\circ 5'$. Hence $Z \perp a(100)$ nearly. Dispersion inclined, strongly marked, of the axes feeble, $p > v$. Axial angle large. $\alpha = 1.729$ $\beta = 1.754$ $\gamma = 1.768$. Indices and birefringence variable, rising in values with increase in iron content.

Var. — Epidote has ordinarily a peculiar yellowish green (epidotic) color, seldom found in other minerals. But this color passes into dark and light shades — black on one side and brown on the other, red, yellow and colorless varieties also occur.

Var. — 1. Ordinary. Color green of some shade as described, the pleochroic tint rarely absent. In the variety (6) from the Canadian massive and Scotch epidote apart from the green, washiness in various shades. The Archaic, Norway, epidote are almost entirely in dark green crystals (that of Bourg d'Oisans, Isere, France, and of dolphonic oolite), in yellowish green crystals, and are transparent. Panchinite includes crystals from the Archaic sapls of Ekerup, Ural Mts. Archaic is ordinary epidote from Archaic, Ural Mts. A variety from Gardia, Heston Island, Terra del Fuoco, is colorless or, in some places, colorless.

2. The black out of Archaic, Ural Mts. described by Hermann is black with a tinge of green, and differs from ordinary epidote in having the crystals nearly symmetrical and not, like other epidote, elongated in the direction of the c -axis. $G = 3.51$.

3. **Wahning.** — Carmine-red or straw-yellow strongly pleochroic deep crimson and straw yellow. $H = 6-6.5$ $G = 3.14$. In small rounded grains. From Cumbria, in Argyleshire, Scotland. Sometimes referred to panchinite, but contains a little Mn.

4. **Panchinite** or **chromite** is a chromium-bearing epidote from Tawehaw, Kachin Hills, Upper Burma. Deep green color and strong pleochroism, emerald-green to bright yellow.

Comp. — $\text{HCa}_2(\text{Al}, \text{Fe})\text{Si}_2\text{O}_6$ or $\text{H}_2\text{O} 4\text{CaO} 3(\text{Al}, \text{Fe})_2\text{O}_3 6\text{SiO}_2$, the ratio of aluminum to iron varies commonly from 5:1 to 3:2. Percentage composition

For A. Fe = 3.1 SiO₂ 37.87, Al₂O₃ 24.13, Fe₂O₃ 12.80, CaO 23.51, H₂O 1.80 = 100.

X-ray study shows two such molecules in the unit cell of the structure.

Panchinite is supposed to contain 34g in place of Ca.



Cleavage: $a(100)$ and $c(001)$ in traces also in 110 sometimes observed
 fracture uneven or subconchoidal Brittle $H = 5.5$ to 6 $G = 3.0$ to 4.2
 luster submetallic, pitchy to resinous Color brown to black. St translucent to opaque Pleochroism strong Z brownish yellow Y reddish brown,
 X greenish brown. Typically Ax pleochroism (100) , sometimes (100)
 $A \wedge c$ axis = 32° approx. $2V$ large. In gems vary widely, 1 to 150° . Bi-
 refringence variable. Almandine is easily altered and then the mineral usually
 becomes isotropic with lower specific gravity and refractive index. Very
 commonly almandine shows a heterogeneous mixture of unaltered and altered
 material. Almandine embedded in biotite may produce a pleochroic halo in
 the latter mineral.

Var. - albanus - The original material was from East Greenland in tabular crystals of purest, colorless, or nearly white, CaF_2 (1895-96). It is similar to and is from albanite in some form, but is thought to have been derived from the Norwegian *Bergströmite* variety 1. It is a mineral which are like the background of a *Bergströmite* type 10.

Polypodium is derived from a compound use by Linnaeus or in earlier times for the crutch, containing some water from the mountain near him. Some say that these plants are common to all forms, and some with us are apocryphal, or as nearly so as most plants. The name is from *apocryphus*.

Comp. — Like epitote $\text{HfR}_2\text{Si}_2\text{O}_7$ or $\text{H}_2\text{O} 4\text{RO} 3\text{R}_2\text{O}_7 6\text{SiO}_2$ with R = Ca and Fe, and $\text{R}' = \text{Al}$ Fe. The cerium metals Ce, Th, La, and in smaller amounts those of the yttrium group. Some varieties contain considerable water, but probably by alteration.

Pyrr. etc. Some varieties give much water in the closed tube, and all sorts yield a small amount on strong action. All leaves easily and freely $1 = 5$ to a dark, highly magnetic glass. With the fluxes results for iron. Most varieties gelatinize with hydrochloric acid, but if the acids are not decomposed $1 = 2$ to a

Obs. A large, flat elliptical crystal is found as an accessory mineral in the deep-seated igneous rocks, to granite, a basic diorite, and a pegmatite. Either in the volcanic rocks that have been derived from igneous rocks, or in the plutonic, or in volcanic ejecta and has been found in association with a contact aureole. With marginal bodies. Sometimes occurs as a mineral in veins of the metamorphic rocks, especially in the

[illegible]

In the United States a rare occurs in New York in large crystals with magnetite as Mn-rich, Essex Co., and in Orange Co. at Monroe and at Ferrisville near Warwick. At Elm Hill Sussex Co., New Jersey. In Pennsylvania: Chester Co., as elsewhere. In large masses in Ashcroft, Virginia, and also from Amelia Court House, Amelia Co. At the sandstone quarry in Llano Co., Texas.

ANALYSIS. A silicate and phosphate of aluminum, rare earths, calcium and iron. Monobasic. In small prismatic crystals or tabular masses. $H_2O = 1.75$, $Si = 1.75$. H_2O reactive. Color black. Resinous luster. Ax pt. 013. $n = 1.700$, $n_g = 1.700$, $n_e = 1.700$. Triclinic. $X =$ prismatic, $Y =$ vertical, $Z =$ rare lat. axes. $Z =$ pale yellow. Found in pegmatite near Nyagatare, Kivu area, banding 1 on the N. in pegmatite, Japan. Considered to be a member of the Epidote group, related to allanite.

IV. Subsilicates

The species here included are basic salts, for the most part to be referred either to the metasilicates or orthosilicates, like many basic compounds already included in the preceding pages. Until their constitution is definitely settled, however, they are more conveniently grouped by themselves as **STRASILICATES**.

The only prominent group in this subdivision is the **Humite Group**.

Humite Group

| | | <i>a</i> | <i>b</i> | <i>c</i> | β |
|-------------------------------|--------------|----------|----------|----------|---------|
| Norbergite | | | | | |
| $Mg_2SiO_4 \cdot Mg(F,OH)_2$ | Orthorhombic | 1.086 | 1 | 1.897* | — |
| | | (1.10) | 1 | 1.897† | — |
| Chondrodite | | | | | |
| $2Mg_2SiO_4 \cdot Mg(F,OH)_2$ | Monoclinic | 1.0863 | 1 | 3.1447 | 90° |
| Humite | | | | | |
| $3Mg_2SiO_4 \cdot Mg(F,OH)_2$ | Orthorhombic | 1.0802 | 1 | 4.4033 | — |
| Clinohumite | | | | | |
| $4Mg_2SiO_4 \cdot Mg(F,OH)_2$ | Monoclinic | 1.0803 | 1 | 5.6588 | 90° |

The species here included form a remarkable series both as regards crystalline form and chemical composition. In crystallization they have sensibly the same ratio for the lateral axes, while the vertical axes are almost exactly in the ratio of the numbers 3 5 7 9 (see also below). Furthermore, though two species are orthorhombic, and two are monoclinic, they here also correspond closely, since the axial angle β in the latter cases does not sensibly differ from 90°. Goldschmidt changes the crystal orientation of the members of this group by interchanging the *a* and *c* axes. This position is in accord with the results of the X-ray investigation of these minerals.

Its composition, as was shown by Penfield and Howe (also Sjoegren) that the last three species were basic orthosilicates in each of which the anionic group MgF^- or $(MgOH)^-$ entered, while the Mg_2SiO_4 groups present were in the ratio of 2 : 3 : 4. From these facts it was predicted that a member of the group, then unknown, would be found in which the ratios would give only Mg_2SiO_4 . This mineral, known as **norbergite**, has recently been discovered. In physical characters these species are very similar, and several of them may occur together at the same locality and even intercrystallized in parallel lamellae.

The species of the group approximate closely in angle and structure to chrysotholite. The axial ratios may be compared as follows:

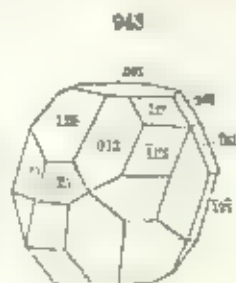
| | | | | | |
|---------------|----------|------------|----------|----------------|---------------|
| Norbergite | <i>a</i> | <i>b</i> | <i>c</i> | $\frac{b}{a}$ | $\frac{c}{a}$ |
| Chondrodite | <i>a</i> | <i>b</i> | <i>c</i> | $\frac{b}{a}$ | $\frac{c}{a}$ |
| Humite | <i>a</i> | <i>b</i> | <i>c</i> | $\frac{b}{a}$ | $\frac{c}{a}$ |
| Clinohumite | <i>a</i> | <i>b</i> | <i>c</i> | $\frac{b}{a}$ | $\frac{c}{a}$ |
| Chrysotholite | <i>b</i> | 2 <i>a</i> | <i>c</i> | $\frac{b}{2a}$ | $\frac{c}{a}$ |

In the atomic structure there are independent SiO_4 groups. Each oxygen atom is linked to one silicon and three magnesium atoms. The latter is with a group of six oxygen atoms. The units separate a mass up of at least layers composed of alternating silicate identical with their crystalline structure. Between these layers lie other layers containing the F or OH groups. The different members of the group vary in their structure by the fre-

* Theoretical value as derived by Penfield and Howe

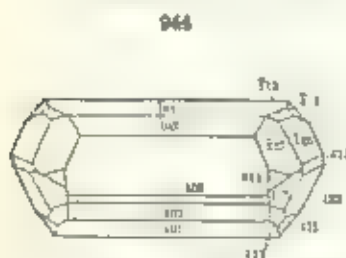
† From measured crystals from Franklin, New Jersey

Chondrodite occurs at Mte. Somma, in Limb. de Joazez, Malaga, Spain, as polysynthetic lamellæ in *parietes intercrossed* with barite, in crystalline limestone near Lake Baikal, Siberia. At Brewster Pluton, Co. New York, in rare but highly magnesian crystals. *Tetrahimant* (as is a tetartohedral variety) originates chiefly from the Ann valley, Prussia, &c.



Figs. 941, 942, *Chondrodite*, Brewster, N. Y.

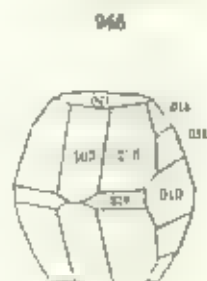
Chondrodite, Sweden.



Projection on (100)

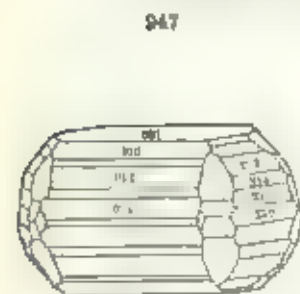


Projection on (010)



Figs. 944, 945 *Chondrodite*, Mte. Somma

Humite, Sweden



Humite, Veauville



Chondrodite, Brewster



Projection on (010)

Chondrodite, Mte. Somma

Numerous other localities of *chondrodite* have been noted, chiefly in crystalline limestone; most of these are probably to be referred to the species *chondrodite*, but the locality in many cases is not proved. At Brewster Pluton (Co. New York), large quantities of mal-

Aperthite. Also in France from Hautes-Alpes, from the island of Corsica from New Caledonia.

Hyalite. — Synonym for hyaloprite. H_2O a hydrous silicate. In minute isometric crystals, usually octahedral, $H = 6$, $G = 5.5$. Color pale green. Optical properties: $n = 1.47$. It is from the district of Marienberg near Völs in the Tyrol of Carinthia and associated with mica. It also occurs in the same district in the form of a fine, fibrous variety.

Urtite. A silicate of the cerium minerals with water. Tetragonal or orthorhombic crystals with sharp edges. $H = 5.5$, $G = 4.9$. Color between chestnut-brown and chocolate to gray. Luster glassy with small optical angle. $n_x = 1.5$, $n_y + n_z = 1.62$. Occurs at Ilmenau near Rudolstadt, Thuringia, and, Sweden.

Torbernite. — A silicate of the cerium minerals, chiefly R_2O and SO_3 . Monoclinic, $H = 4.5$, $G = 4.0$. Color, green to olive. $d = .85$. Luster vit. Fracture conchoidal. $n = 1.42$. Occurs at Bastnäs in the near Rudolstadt in Thuringia and in Sweden.

Berkelite. As_2O_5 and As_2O_3 . Isometric crystals small, often microscopic. $H = 5$, $G = 4.5$. Color, yellow. $n = 1.412$. Occurs in the near Rudolstadt rocks near Marienfeld, on the north shore of the Sea of Azov, Ukraine, Russia.

Urtite. A silicate of calcium and the rare earths. $H = 4.5$, $G = 4.7$. Color green to reddish with wavy lines of color. $d = .85$. Luster vit. Fracture conchoidal. $n = 1.42$. Occurs at Ilmenau near Rudolstadt, Thuringia, and, Sweden.

Urtite. A silicate and borate of aluminum, vitrium, manganese and iron. Isometric habit. $H = 4.5$, $G = 4.7$. Color, deep red. Fracture conchoidal. Occurs at Ilmenau near Rudolstadt, Thuringia, and, Sweden.

Hyalite. A silicate of cerium and the rare earths. Isometric habit. $H = 5$, $G = 4.5$. Color, yellow. $n = 1.412$. Occurs in the near Rudolstadt rocks near Marienfeld, on the north shore of the Sea of Azov, Ukraine, Russia.

Bastnaesite. A silicate of cerium and the rare earths, iron and a little soda. Hexagonal. $H = 4.5$, $G = 4.7$. Color, green to reddish. $d = .85$. Luster vit. Fracture conchoidal. $n = 1.42$. Occurs at Bastnäs in the near Rudolstadt, Thuringia, and, Sweden.

Urtite. A silicate of cerium and the rare earths, iron and a little soda. Hexagonal. $H = 4.5$, $G = 4.7$. Color, green to reddish. $d = .85$. Luster vit. Fracture conchoidal. $n = 1.42$. Occurs at Bastnäs in the near Rudolstadt, Thuringia, and, Sweden.

Urtite. A silicate of cerium and the rare earths, iron and a little soda. Hexagonal. $H = 4.5$, $G = 4.7$. Color, green to reddish. $d = .85$. Luster vit. Fracture conchoidal. $n = 1.42$. Occurs at Bastnäs in the near Rudolstadt, Thuringia, and, Sweden.

TOURMALINE. Turmalin.

Rhombohedral-hemimorphic. Axis $c = 0.4177$

| | | |
|------------------------------------------------|------------------------------------------------|------------------------------------------------|
| α (100) \wedge (101) = $2^\circ 30'$ | α (101) \wedge (110) = $46^\circ 32'$ | α (110) \wedge (111) = $66^\circ 1'$ |
| α (001) \wedge (021) = $45^\circ 57'$ | α (021) \wedge (202) = $77^\circ 0'$ | α (202) \wedge (021) = $42^\circ 36'$ |

Crystals usually prismatic in habit, often slender to acicular, rarely flattened, the prism nearly wanting. Prismatic faces sharply striated vertically and the crystals hieroglyphic, rounded to barrel shaped. The cross section of the prism three-sided (see Fig. 960), six-sided m , or nine-sided n and o . Crystals commonly hemimorphic. Sometimes isolated, but more commonly in parallel or radiating groups. Sometimes massive compact, also columnar coarse or fine, parallel or divergent.

Fracture, α (110), α (111) difficult. Fracture rhombohedral to uneven. Brittle and often rather friable. $H = 7-7.5$, $G = 2.98-3.20$. Luster vitreous to resinous. Color black, brownish black, bluish black, most common blue, green, red, and sometimes of rich shades, rare white or colorless, some specimens red internally and green externally, and others red at one

Comp. — A complex silicate of boron and aluminum, with also other magnesium silicates. The formula is $\text{B}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot \text{Al}_2\text{O}_3 \cdot 2\text{H}_2\text{O}$. A general formula may be written as $\text{H}_2\text{B}_2\text{O}_4 \cdot \text{R}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$, where R represents the other metal ions present in the crystal lattice. The formula is also written as $\text{H}_2\text{B}_2\text{O}_4 \cdot \text{R}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$.

Minerals of this group are usually green to black, and are found in a variety of rocks. They are usually found in the form of small, prismatic crystals.

The color of these minerals is usually green to black, and they are often found in the form of small, prismatic crystals. The color of these minerals is usually green to black, and they are often found in the form of small, prismatic crystals.

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[illegible]

In the United States, tourmaline is common in the pegmatites of southeastern Maine, the chief localities being at the following places: 1. The large green tourmaline crystals of the Maine tourmaline belt, which extends from Newry in the north to Bangor in the south. 2. The large green tourmaline crystals of the Bangor tourmaline belt, which extends from Bangor in the north to Newry in the south. 3. The large green tourmaline crystals of the Bangor tourmaline belt, which extends from Bangor in the north to Newry in the south. 4. The large green tourmaline crystals of the Bangor tourmaline belt, which extends from Bangor in the north to Newry in the south. 5. The large green tourmaline crystals of the Bangor tourmaline belt, which extends from Bangor in the north to Newry in the south. 6. The large green tourmaline crystals of the Bangor tourmaline belt, which extends from Bangor in the north to Newry in the south. 7. The large green tourmaline crystals of the Bangor tourmaline belt, which extends from Bangor in the north to Newry in the south. 8. The large green tourmaline crystals of the Bangor tourmaline belt, which extends from Bangor in the north to Newry in the south. 9. The large green tourmaline crystals of the Bangor tourmaline belt, which extends from Bangor in the north to Newry in the south. 10. The large green tourmaline crystals of the Bangor tourmaline belt, which extends from Bangor in the north to Newry in the south.

The above information was obtained from a phone interview to the jewellers of the town.

Use of _____ covered and transparent surface and glass as given above and under 4a. above.

under "Vns above.
Pumpkinseed. A fine specimen from Lawrence portage N.Y. Oct 26-73.
The head and eye are very large and the scales are small. The
faintly colored. The body is yellowish white. The fins are small and
the scales are small.

[illegible]

... and in thin section by its rather rough, rounded, low interference colors, the ...

In New York it occurs from Albany southward to New York City and westward to Buffalo. It is also found in the Adirondacks. In Canada it occurs in Ontario.

STAUROLITE Staurolithe

Orthorhombic Axes a b c = 0.4734 1 0.6828

02700 13 170 = 53 40

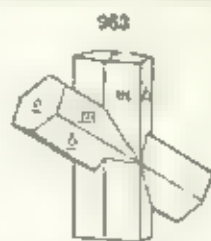
$$\pi_0 : \{01\} \wedge \bar{\{01\}} = 11, \quad 36.$$
$$\sigma_{\text{eff}}(0) = 10^{-10} \text{ cm}^2$$

ref 10 3 10 4

Twins on {101} in pl. 2032, the crystals crossing nearly at right angles might also be explained as having a $\{101\} \parallel 100^\circ$ and a $\{101\} \parallel 90^\circ$ between in crystal 1, tw. pl. = 2320 crossing at an angle of 90° approximately (may also be explained as a rotation of 120° about the zone axis 100°).

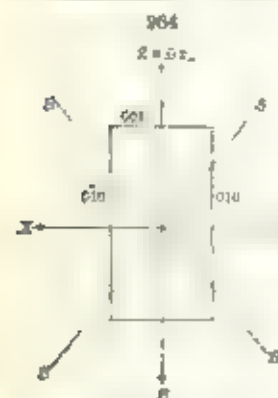
tw pl $\mu(230)$ rare, also in repeated twins (cf. Figs. 423, p. 185, 465, 486, 467, p. 191). Crystals commonly prismatic and flattened on b axis, often with rough surfaces.

X-ray structure of staurolite shows that it has in part an atomic arrangement identical with that of kyanite. It may be conceived as made up of



layers lying perpendicular to the b axis, that show the structure of kyanite, alternating with layers that contain iron atoms and hydroxyl groups. The atomic arrangement on the told face of staurolite is identical with that on the $\{100\}$ face of kyanite, thus explaining the parallel crystallization of the two minerals frequently observed. The unit cell contains four molecules. Its dimensions correspond to 1a, 1b, 1c.

Fracture: $b(010)$ distinct but interrupted, $m(110)$ in traces. Fracture subconchoidal. Brice: $H = 7.75$. $G = 3.65-3.77$. S : vitreous, inclining to resinous. Color dark reddish brown to brownish black and yellowish brown. S reak: color red to grayish. Lustrous: to nearly or quite opaque. Pleochroism: distinct. $Z = c$ axis hyacinth-red to blood-red, X, Y yellowish red, or Z gold-yellow, X, Y light yellow or colorless. Ox : nearly +. Ax pl: $a(100)$, $Z \perp c(001)$. $2V = 88$ (approx). $\alpha = 1.730$, $\beta = 1.741$, $\gamma = 1.746$.



Comp. — $[(Fe, Al)Si_2O_6]_n$, which may be written $(Al)_1, (Fe, Al)_{1-x}Si_2O_6$, or $(Fe, Al)_{1-x}Si_2O_6$. S (approx) 20.3, S (approx) 55.9. Iron protoxide 15.8, water 2.0 = 100. Manganese (also manganese) replaces a little of the ferric iron, part of the aluminum.

As a result of X-ray study the following new formula has been proposed: $[(Fe, Al)Si_2O_6]_n$. In order to show the relation to kyanite, this may be written $2AlSi_2O_6, 1c(010)$. Variations in composition from $2AlSi_2O_6$ to $2FeSi_2O_6$ are supposed to be due to the presence of iron, common to kyanite.

Notes: — (1) X-ray study shows that the manganese is a large amount. (2) Fe, Al etc. (3) It differs in exhibiting the pleochroism variety which is easily to a black magenta color. (4) W, b etc. axis gives red color for iron, and sometimes for manganese. In particular, from iron by pleochroism.

Diff. — It has been noted by the absence of pleochroism which is nearly square by the frequency of twinning forms, by hardness and its quality.

Micro — In thin sections, staurolite is a colorless to yellow to red or brown, strong pleochroism, yellow and red, and sometimes by strong refraction. Light refraction is high. Refraction is parallel to the c axis, character generally positive in the direction of elongation. It is distinguished from rutile (p. 438) by its high refractive index not lower than rutile colors.

Obs. — Usually found in crystalline schists, as mica schist, phyllite, and gneiss, as a result of regional or more rarely of contact metamorphism, often associated with garnet,

Xenothla. $5\text{CaSiO}_3 \cdot \text{H}_2\text{O}$. Massive in matted fibers, or from Virginia in needles. One good cleavage. $\mu = 1.58$, $\rho = 1.58$, $\gamma = 1.58$. 25 very small. Occurs at Xenothla, Mexico; also from Scotland and at Leesburg, Virginia. Martin's name Santa Ynez, Santa Ynez Co., California, and Lake Rosan, Michigan, described under the name *aukards*, 1850.

Cresimareite. $\text{Pb}(\text{OH})_2 \cdot 2\text{H}_2\text{O}$. Monoclinic. Compact. Color snow-white. $H = 3$. $\rho = 2.2$. Lustrous. Cleavage usually $\mu = 1.593$, $\rho = 1.593$, $\gamma = 1.593$. 25 large. An alternate name is *resimareite*. From a rock at Riverside, California. **Riversideite.** $\text{Pb}(\text{OH})_2 \cdot 2\text{H}_2\text{O}$. Orthorhombic? In compact fibrous crystals. $H = 3$. $\rho = 2.2$. Lustrous. Cleavage usually $\mu = 1.593$, $\rho = 1.593$, $\gamma = 1.593$. 25 large. From a rock at Riverside, California.

Centallaite. $\text{Pb}(\text{OH})_2 \cdot 2\text{H}_2\text{O}$. Prismatic or lamellar to compact. $H = 2.5$. $\rho = 2.51$. Lustrous. Cleavage usually $\mu = 1.593$, $\rho = 1.593$, $\gamma = 1.593$. 25 small. Found in the hills of the region of Nevada and it is frequently like in appearance to quartz at Cresimare. **Centallaite.** $\text{Pb}(\text{OH})_2 \cdot 2\text{H}_2\text{O}$.

Interspersite. $\text{Pb}(\text{OH})_2 \cdot 2\text{H}_2\text{O}$. Color white. From a rock at Riverside, California. $H = 2.5$. $\rho = 2.51$. Lustrous. Cleavage usually $\mu = 1.593$, $\rho = 1.593$, $\gamma = 1.593$. 25 very small. As spherical aggregates from the Lake County, California. **Interspersite.** $\text{Pb}(\text{OH})_2 \cdot 2\text{H}_2\text{O}$.

Ganophyllite. $\text{Pb}(\text{OH})_2 \cdot 2\text{H}_2\text{O}$. Monoclinic. In short prismatic crystals. $H = 3$. $\rho = 2.2$. Lustrous. Cleavage usually $\mu = 1.593$, $\rho = 1.593$, $\gamma = 1.593$. 25 small. Found in the hills of the region of Nevada and it is frequently like in appearance to quartz at Cresimare. **Ganophyllite.** $\text{Pb}(\text{OH})_2 \cdot 2\text{H}_2\text{O}$.

Racemite. A silicate of aluminum and calcium with a large amount of water which is given off readily and without changing the structure or optical properties. Color yellowish but without crystalline form. **Racemite.** $\text{Pb}(\text{OH})_2 \cdot 2\text{H}_2\text{O}$. $H = 2.5$. $\rho = 2.51$. Lustrous. Cleavage usually $\mu = 1.593$, $\rho = 1.593$, $\gamma = 1.593$. 25 small. Found in the hills of the region of Nevada and it is frequently like in appearance to quartz at Cresimare. **Racemite.** $\text{Pb}(\text{OH})_2 \cdot 2\text{H}_2\text{O}$.

Pumpellite. $\text{Pb}(\text{OH})_2 \cdot 2\text{H}_2\text{O}$. Orthorhombic. In compact plates or narrow plates. $H = 3$. $\rho = 2.2$. Lustrous. Cleavage usually $\mu = 1.593$, $\rho = 1.593$, $\gamma = 1.593$. 25 large. Strong absorption $\rho < \mu$. $\mu = 1.593$, $\rho = 1.593$, $\gamma = 1.593$. 25 large. Found in the hills of the region of Nevada and it is frequently like in appearance to quartz at Cresimare. **Pumpellite.** $\text{Pb}(\text{OH})_2 \cdot 2\text{H}_2\text{O}$.

Louite. $\text{Pb}(\text{OH})_2 \cdot 2\text{H}_2\text{O}$. Massive. In an aggregate of small grains and leaves. $H = 3$. $\rho = 2.2$. Lustrous. Cleavage usually $\mu = 1.593$, $\rho = 1.593$, $\gamma = 1.593$. 25 small. Found in the hills of the region of Nevada and it is frequently like in appearance to quartz at Cresimare. **Louite.** $\text{Pb}(\text{OH})_2 \cdot 2\text{H}_2\text{O}$.

Okenite. $\text{Pb}(\text{OH})_2 \cdot 2\text{H}_2\text{O}$. Massive. In massive blade-shaped crystals. $H = 3$. $\rho = 2.2$. Lustrous. Cleavage usually $\mu = 1.593$, $\rho = 1.593$, $\gamma = 1.593$. 25 small. Found in the hills of the region of Nevada and it is frequently like in appearance to quartz at Cresimare. **Okenite.** $\text{Pb}(\text{OH})_2 \cdot 2\text{H}_2\text{O}$.

Gyrolite. $\text{Pb}(\text{OH})_2 \cdot 2\text{H}_2\text{O}$. Rhombohedral tetrahedral. In white crystalline, lamellar crystals. $H = 3$. $\rho = 2.2$. Lustrous. Cleavage usually $\mu = 1.593$, $\rho = 1.593$, $\gamma = 1.593$. 25 small. Found in the hills of the region of Nevada and it is frequently like in appearance to quartz at Cresimare. **Gyrolite.** $\text{Pb}(\text{OH})_2 \cdot 2\text{H}_2\text{O}$.

Zeolite. A silicate of aluminum and calcium with a large amount of water which is given off readily and without changing the structure or optical properties. Color yellowish but without crystalline form. **Zeolite.** $\text{Pb}(\text{OH})_2 \cdot 2\text{H}_2\text{O}$. $H = 2.5$. $\rho = 2.51$. Lustrous. Cleavage usually $\mu = 1.593$, $\rho = 1.593$, $\gamma = 1.593$. 25 small. Found in the hills of the region of Nevada and it is frequently like in appearance to quartz at Cresimare. **Zeolite.** $\text{Pb}(\text{OH})_2 \cdot 2\text{H}_2\text{O}$.

the French Creek mines, Chester Co. With the copper deposits of Keweenaw Co., Michigan, at the Lake Superior side of the Superior basin. It is also an important ore of lead at the mercury mines of New Mexico with various very often associated minerals.

In the U.S.A. it is found in the New England area, and in the West, mainly in the Lake States, Cape May, Cape Split, Cape Blomidon, etc.

Various other localities are known to be important, but the list would be too long to give. The mineral is also found in the U.S.A. in the West, mainly in the Lake States, Cape May, Cape Split, Cape Blomidon, etc.

2. Zeolites

The ZEOLITES form a family of well-defined hydrous silicates, closely related to each other in composition, in conditions of formation, and hence in mode of occurrence. They are first well spoken of as analogous to the Feldspars, like which they are, silicates of an alumin with sodium, and calcium elements, also rarely barium, and strontium, magnesium, iron, etc., are absent or present only through impurity or in trace. Further, the composition of a number of species corresponds to that of a hydrated ferrosilicate, while fusion and slow recrystallization result in a formation of some silicate of anorthite ($\text{CaAl}_2\text{Si}_2\text{O}_8$) or even up to $\text{CaAl}_2\text{Si}_2\text{O}_8$ is shown by reaction. The theory has been advanced by Winchell that the zeolites are $\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot \text{SiO}_2 \cdot n\text{H}_2\text{O}$, and that in any given polymorphous part of the Zeolite Group the $\text{Ca} + \text{Na}$ ratio is constant. The first rule is confirmed by G. Tschermak, who further concludes that all zeolites contain either $\text{CaAl}_2\text{Si}_2\text{O}_8$ or $\text{Na}_2\text{Al}_2\text{Si}_2\text{O}_8$ combined with a silicic acid, by hydroxyl and water of crystallization. The Zeolites do not, however, form a single group of species related in crystallization like the Feldspars, but include a number of independent groups widely diverse in form, and distinct in composition, chief among these are the monoclinic PHILIPPE GROUP, the orthorhombic CHABAZITE GROUP, and the orthorhombic and monoclinic NATROLITE GROUP. A transition in composition between certain end compounds has been more or less well established in certain cases, but, unlike the Feldspars, with these species calcium and sodium, seem, to replace one another and an increase in alkali does not necessarily go with an increase in silica.

The water contained in the zeolites differs from the ordinary water of crystallization of other minerals. When the zeolites are heated the water is given off readily and continuously and not in certain amounts at definite temperatures as is usually the case. Further, the normally dehydrated mineral can again take up an equal amount of water if exposed to water vapor. The optical characters change gradually on dehydration, but apparently the atomic structure (as shown by X-ray study) remains the same unless the process is carried nearly to completion. Further, the partially dehydrated mineral can absorb other materials in place of the water, such as ammonia, methyl hydrogen sulphide, iodine, etc. It would appear that the water occupies at least an important position in the atomic structure of the zeolites, possibly being present as adsorbed water held in openings or cavities of the structure (see further under ion-exchange, p. 672). An interesting peculiarity is the fact that the alkali metal present may be artificially replaced by silver and other metals.

Like other hydrous silicates they are characterized by a lower hardness, chiefly from 3.5 to 5.5, and the specific gravity is lower than that with corresponding anhydrous species, chiefly 2.0 to 2.4. Corresponding to these charac-

test they are rather readily decomposed by acids, many of them with gelatinization. The antiseptics B 15 which gives the name to the family from *Salmonella* and *Yersinia*, alone, are characteristic of a large part of the species.

The Zonedals are all secondary minerals, occurring most abundantly in contact and veins in basic igneous rocks, in basic dikes, etc. They are frequently in granite, gneiss, etc. In some cases the ore and the matrix in part have been entirely replaced by the talc zone, the soda, etc. replacement, and the talc zone is in the matrix. The different species of the talc zone are associated with each other, also with peridot and spinel, etc. Some are associated with the zonedals, talc, etc., peridot, etc. Many of the zonedals have been produced synthetically by various methods, etc. In general they appear to have been formed in nature by reactions upon the talc, etc. or talc, etc. and minerals.

Mordenite Group

Considerable confusion exists as to the relationships of the three following species. Schaller (1893) is of the opinion that the form with the composition $\text{Na}_2\text{Na}_2\text{Al}_2\text{O}_6\text{H}_2\text{O}$ is a true crystalline form with an apparent extinction about 5°. He further considers it to have 188.4 and 71.0 to be identical with the present extinction, and to be the most common member of the group. The mineral described by Passon from Wyoming and accepted by Dana as crystallized halite he considers to be a different form or polymorph of halite, with a large extinction angle and gives it the name *disphalite*. On the other hand, Breght considers it to be identical with present and Wager and Passon suggest that it is identical with *isordite*.

Pilotair - (A) 1. 2. 3. 4. 5. 6. 7. 8. 9. 10. 11. 12. 13. 14. 15. 16. 17. 18. 19. 20. 21. 22. 23. 24. 25. 26. 27. 28. 29. 30. 31. 32. 33. 34. 35. 36. 37. 38. 39. 40. 41. 42. 43. 44. 45. 46. 47. 48. 49. 50. 51. 52. 53. 54. 55. 56. 57. 58. 59. 60. 61. 62. 63. 64. 65. 66. 67. 68. 69. 70. 71. 72. 73. 74. 75. 76. 77. 78. 79. 80. 81. 82. 83. 84. 85. 86. 87. 88. 89. 90. 91. 92. 93. 94. 95. 96. 97. 98. 99. 100. 101. 102. 103. 104. 105. 106. 107. 108. 109. 110. 111. 112. 113. 114. 115. 116. 117. 118. 119. 120. 121. 122. 123. 124. 125. 126. 127. 128. 129. 130. 131. 132. 133. 134. 135. 136. 137. 138. 139. 140. 141. 142. 143. 144. 145. 146. 147. 148. 149. 150. 151. 152. 153. 154. 155. 156. 157. 158. 159. 160. 161. 162. 163. 164. 165. 166. 167. 168. 169. 170. 171. 172. 173. 174. 175. 176. 177. 178. 179. 180. 181. 182. 183. 184. 185. 186. 187. 188. 189. 190. 191. 192. 193. 194. 195. 196. 197. 198. 199. 200. 201. 202. 203. 204. 205. 206. 207. 208. 209. 210. 211. 212. 213. 214. 215. 216. 217. 218. 219. 220. 221. 222. 223. 224. 225. 226. 227. 228. 229. 230. 231. 232. 233. 234. 235. 236. 237. 238. 239. 240. 241. 242. 243. 244. 245. 246. 247. 248. 249. 250. 251. 252. 253. 254. 255. 256. 257. 258. 259. 260. 261. 262. 263. 264. 265. 266. 267. 268. 269. 270. 271. 272. 273. 274. 275. 276. 277. 278. 279. 280. 281. 282. 283. 284. 285. 286. 287. 288. 289. 290. 291. 292. 293. 294. 295. 296. 297. 298. 299. 300. 301. 302. 303. 304. 305. 306. 307. 308. 309. 310. 311. 312. 313. 314. 315. 316. 317. 318. 319. 320. 321. 322. 323. 324. 325. 326. 327. 328. 329. 330. 331. 332. 333. 334. 335. 336. 337. 338. 339. 340. 341. 342. 343. 344. 345. 346. 347. 348. 349. 350. 351. 352. 353. 354. 355. 356. 357. 358. 359. 360. 361. 362. 363. 364. 365. 366. 367. 368. 369. 370. 371. 372. 373. 374. 375. 376. 377. 378. 379. 380. 381. 382. 383. 384. 385. 386. 387. 388. 389. 390. 391. 392. 393. 394. 395. 396. 397. 398. 399. 400. 401. 402. 403. 404. 405. 406. 407. 408. 409. 410. 411. 412. 413. 414. 415. 416. 417. 418. 419. 420. 421. 422. 423. 424. 425. 426. 427. 428. 429. 430. 431. 432. 433. 434. 435. 436. 437. 438. 439. 440. 441. 442. 443. 444. 445. 446. 447. 448. 449. 450. 451. 452. 453. 454. 455. 456. 457. 458. 459. 460. 461. 462. 463. 464. 465. 466. 467. 468. 469. 470. 471. 472. 473. 474. 475. 476. 477. 478. 479. 480. 481. 482. 483. 484. 485. 486. 487. 488. 489. 490. 491. 492. 493. 494. 495. 496. 497. 498. 499. 500. 501. 502. 503. 504. 505. 506. 507. 508. 509. 510. 511. 512. 513. 514. 515. 516. 517. 518. 519. 520. 521. 522. 523. 524. 525. 526. 527. 528. 529. 530. 531. 532. 533. 534. 535. 536. 537. 538. 539. 540. 541. 542. 543. 544. 545. 546. 547. 548. 549. 550. 551. 552. 553. 554. 555. 556. 557. 558. 559. 560. 561. 562. 563. 564. 565. 566. 567. 568. 569. 570. 571. 572. 573. 574. 575. 576. 577. 578. 579. 580. 581. 582. 583. 584. 585. 586. 587. 588. 589. 590. 591. 592. 593. 594. 595. 596. 597. 598. 599. 600. 601. 602. 603. 604. 605. 606. 607. 608. 609. 610. 611. 612. 613. 614. 615. 616. 617. 618. 619. 620. 621. 622. 623. 624. 625. 626. 627. 628. 629. 630. 631. 632. 633. 634. 635. 636. 637. 638. 639. 640. 641. 642. 643. 644. 645. 646. 647. 648. 649. 650. 651. 652. 653. 654. 655. 656. 657. 658. 659. 660. 661. 662. 663. 664. 665. 666. 667. 668. 669. 670. 671. 672. 673. 674. 675. 676. 677. 678. 679. 680. 681. 682. 683. 684. 685. 686. 687. 688. 689. 690. 691. 692. 693. 694. 695. 696. 697. 698. 699. 700. 701. 702. 703. 704. 705. 706. 707. 708. 709. 710. 711. 712. 713. 714. 715. 716. 717. 718. 719. 720. 721. 722. 723. 724. 725. 726. 727. 728. 729. 730. 731. 732. 733. 734. 735. 736. 737. 738. 739. 740. 741. 742. 743. 744. 745. 746. 747. 748. 749. 750. 751. 752. 753. 754. 755. 756. 757. 758. 759. 760. 761. 762. 763. 764. 765. 766. 767. 768. 769. 770. 771. 772. 773. 774. 775. 776. 777. 778. 779. 780. 781. 782. 783. 784. 785. 786. 787. 788. 789. 790. 791. 792. 793. 794. 795. 796. 797. 798. 799. 800. 801. 802. 803. 804. 805. 806. 807. 808. 809. 810. 811. 812. 813. 814. 815. 816. 817. 818. 819. 820. 821. 822. 823. 824. 825. 826. 827. 828. 829. 830. 831. 832. 833. 834. 835. 836. 837. 838. 839.

Fluorene = $C_{15}H_{10}$ (Aromatic, 10 π electrons)
 Perfluorofluorene = $C_{15}F_{10}$ (Aromatic, 10 π electrons)
 Fluorene = $C_{15}H_{10}$ (Aromatic, 10 π electrons)
 Perfluorofluorene = $C_{15}F_{10}$ (Aromatic, 10 π electrons)

[illegible][illegible]

Heulandite Group. Monoclinic

The following minerals show such close relationships in their crystallographic constants and similarities in their composition that it is probable that they form an isomorphous series.

| | | a | b | c | β |
|-------------|---------------------------------------------------|-------|---|-------|-----------------|
| Mordenite | $(Ca, Na_2O) Al_2O_3 \cdot 9SiO_2 \cdot 6H_2O$ | 0.401 | 1 | 0.428 | $88^\circ 31'$ |
| Heulandite | $(Ca, Na_2O) Al_2O_3 \cdot 8SiO_2 \cdot 5H_2O$ | 0.404 | 1 | 0.429 | $88^\circ 34'$ |
| Epistilbite | $(Ca, Na_2O) Al_2O_3 \cdot 6SiO_2 \cdot 5H_2O$ | 0.410 | 1 | 0.432 | $89^\circ 20''$ |
| Brewsterite | $(Sr, Ba, Ca) O Al_2O_3 \cdot 6SiO_2 \cdot 5H_2O$ | 0.405 | 1 | 0.420 | $86^\circ 20'$ |

HEULANDITE. Stilbite some authors

Monoclinic. Axes $a : b : c = 0.4035 : 1 : 0.4203$; $\beta = 88^\circ 34\frac{1}{2}'$.

$$mc', 110 \wedge 1\bar{1}0 = 43^\circ 56'$$

$$ca, 001 \wedge 201 = 65^\circ 40'$$

$$ca, 001 \wedge 201 = 66^\circ 0'$$

$$ca, 001 \wedge 021 = 40^\circ 38'$$

Crystals sometimes flattened $b(010)$, the surface of pearly luster (Fig. 969 also Fig. 21, p. 13), form often suggestive of the orthorhombic system, since the angles ca and ca' differ but little. Also in granular forms granular X-ray study gives a unit cell the dimensions of which are proportional in terms of the above axial ratio to $1a : 1b : 2c$.

Cleavage $b(010)$ perfect. Fracture subconchoidal to uneven. Brittle. $H = 3.5-4$. $G = 2.18-2.22$. Luster of b strong pearly, of other faces vitreous. Color various shades of white, passing into red, gray and brown. Streak white. Transparent to subtranslucent. Opacely + Ax pl and $Z \perp b(010)$. Ax pl and X for some localities nearly $c(001)$, none for others nearly $1 : c$ in white light. Axial angle variable, from 0 to 82° ; usually $2V$ nearly 34° . $\alpha = 1.498$. $\beta = 1.499$. $\gamma = 1.505$.

Comp. — $(Ca, Na_2O) Al_2O_3 \cdot 8SiO_2 \cdot 5H_2O = Silica\ 59.2$, alumina 10.8 , lime 9.2 , water $14.8 = 100$

Strontium is usually present, amounting up to 8.6 per cent.

When heulandite is heated from 25 to $100^\circ C$ there is a gradual and progressive rotation of the axial plane with a decrease in the axial angle, which at a heated to higher temperatures the rotation of the axial plane is more rapid, until the axial angle increases. This change of 10° is due to the formation of the three monomeric hydrate molecules. It is always better preserved in the fibrous or always parallel to the c axis. Above 177° the structure of heulandite breaks down, although the effect of this is apparent in the optical tests only after the specimen has stood for a considerable period of time.

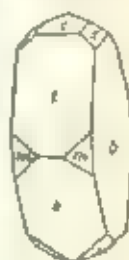
Pyx. b with ad etc. p. 648

Obs. — Heulandite occurs principally in cavities in basaltic and rhyolitic rocks, associated with chlorite, stilbite and other zeolites. It may also occur in other volcanic rocks, in granites and pegmatites, more rarely in gneisses or crystalline schists. Occasionally a quartziferous veins.

The finest specimens of this species come from Iceland at Berufjord and Thenghorn in Iceland islands near Hvalba, and at Lonsund and Pooms and in the Western Gales of Svalby. In Europe it occurs at Amsterg in the Harz Mts., in Val d'Aoste, Trentino, Italy, in Switzerland at Gabe, and near Fiesch in the Rhone valley, Valais, and elsewhere. From Scotland at Campden Hills. Strong red variety with red stalks and at Ardnamurchan near Oban. From the Faroe Islands.

* The original crystallographic orientation of epistilbite has been changed in order to show its relationship to this group.

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In the United States with the trap rocks of northeastern New Jersey at Bergen Hill, West Paterson and Great Notch. In many crystals *beudantic* at Jagers Falls, near Badmore, Maryland. In the Bay of Fundy district, Nova Scotia, at Peter's Point, also at Cape Blomidon. In the Harz Mountains, Germany, at Peter's Point, also at Cape Blomidon. In the Harz Mountains, Germany, at Peter's Point, also at Cape Blomidon.

Named in honor of the English mineralogical collector, H. Beudant, whose cabinet was the largest herminian with 1867 of 1867.

Euphrasite $\text{Ba}_2\text{Ca}_2\text{Al}_2\text{Si}_2\text{O}_{10} \cdot 5\text{H}_2\text{O}$. Monoclinic, uniaxially optically negative. In rare cases adjacent to *beudantic*, in the same crystal. $\alpha = 1.502$, $\beta = 1.500$, $\gamma = 1.511$, $2V = 41^\circ$. Occurs in Ireland at Berrigall with *beudantic* and at Thungaburg, Teutoburg, and elsewhere in the Harz Mountains, on the Harz Mountains. *Beudantic* is a small dark gray mineral. At the same time it is the *beudantic*. A small *beudantic* is also found in the Harz Mountains. In the Harz Mountains, Germany, at Peter's Point, also at Cape Blomidon. In the Harz Mountains, Germany, at Peter's Point, also at Cape Blomidon.

Brewsterite $\text{Ba}_2\text{Ca}_2\text{Al}_2\text{Si}_2\text{O}_{10} \cdot 5\text{H}_2\text{O}$. Monoclinic, uniaxially optically negative. In rare cases adjacent to *beudantic*, in the same crystal. $\alpha = 1.502$, $\beta = 1.500$, $\gamma = 1.511$, $2V = 41^\circ$. Occurs in Ireland at Berrigall with *beudantic* and at Thungaburg, Teutoburg, and elsewhere in the Harz Mountains, on the Harz Mountains. *Beudantic* is a small dark gray mineral. At the same time it is the *beudantic*. A small *beudantic* is also found in the Harz Mountains. In the Harz Mountains, Germany, at Peter's Point, also at Cape Blomidon. In the Harz Mountains, Germany, at Peter's Point, also at Cape Blomidon.

Phillipsite Group. Monoclinic

| | | a | b | c | β |
|-------------|----------------------------------------------------------------------------------------------------|--------|---|--------|----------------|
| Wellsite | $(\text{Ba}, \text{Ca}, \text{K})_2 \text{Al}_2\text{Si}_2\text{O}_{10} \cdot 3\text{H}_2\text{O}$ | 0.768 | 1 | 1.245 | $53^\circ 27'$ |
| Phillipsite | $(\text{K}, \text{Ca}, \text{Al})_2\text{Si}_2\text{O}_{10} \cdot 4\frac{1}{2}\text{H}_2\text{O}$ | 0.7645 | 1 | 1.2503 | $55^\circ 37'$ |
| Harmotome | $(\text{K}, \text{Ba}, \text{Al})_2\text{Si}_2\text{O}_{10} \cdot 5\frac{1}{2}\text{H}_2\text{O}$ | 0.7632 | 1 | 1.2346 | $55^\circ 10'$ |
| Stubite | $\text{Na}_2(\text{K}, \text{Al})_2\text{Si}_2\text{O}_{10} \cdot 6\text{H}_2\text{O}$ | 0.7623 | 1 | 1.2340 | $50^\circ 50'$ |

The above species, when crystallizing in the monoclinic system, are remarkable for the pseudo-symmetry exhibited by their twinned forms. Certain of these twins are pseudo-orthorhombic, others pseudo-trigonal and more complex twins even pseudo-cubic. Each twin suggests another crystal orientation for the minerals of this group was from 8 to 10 degrees. The pseudo-orthorhombic minerals of the group are probably closely related to the group.

The chemical compositions of the different members of the group have been variously interpreted, and probably different compositions are present. The above formulas are based upon reliable analyses of certain typical occurrences.

Wellsite $\text{Ba}_2(\text{Ca}, \text{K})_2 \text{Al}_2\text{Si}_2\text{O}_{10} \cdot 3\text{H}_2\text{O}$. Sr and Na are present in small amounts. This species is characterized by its *beudantic* habit. Monoclinic, uniaxially optically negative. In rare cases adjacent to *beudantic*, in the same crystal. $\alpha = 1.502$, $\beta = 1.500$, $\gamma = 1.511$, $2V = 41^\circ$. Occurs in Ireland at Berrigall with *beudantic* and at Thungaburg, Teutoburg, and elsewhere in the Harz Mountains, on the Harz Mountains. *Beudantic* is a small dark gray mineral. At the same time it is the *beudantic*. A small *beudantic* is also found in the Harz Mountains. In the Harz Mountains, Germany, at Peter's Point, also at Cape Blomidon. In the Harz Mountains, Germany, at Peter's Point, also at Cape Blomidon.

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Hoguen Hill, West Peterson, Great Patch, Upper Mountain etc. In Pennsylvania at
Frankford near Philadelphia. In Nevada south of the same mountains in the ex of heavy
region in mountainous at Partridge Island, two islands, etc. of various parts in the
Keweenaw and Anishinibew etc.

The name *stroph* is from *στρόφη*, *strophē* and means *turning* from *στρέφω* a *strophō*

Epidesmine Comp. same as for *Epidesma* orthostomale. In more crystals, only the three α and β wing changes at 100°C. and vertical planes $\alpha = 60^\circ$, $\beta = 100^\circ$ fusible with a concurrence of α and β in 100°C. α p. = 146.5, β = 145.5, γ = 145.0. α and β are α and β crystals from Schwanberg, Berg, Saxony. Found at Moore's Station, Mercer Co. New Jersey and at Mt. of Washington.

Scheelite $x \text{UO}_2 \cdot y \text{H}_2\text{O}$ (in the ore) Crystals tabular parallel to h 010
 cleavage perfect; parallel to h 010, $n_p = 1.85$ and $n_e = 1.90$ and $(n_e - n_p) = 0.05$
 $d_{110} = 1.85$ and $d_{010} = 1.90$ At 100°C $\alpha = 1.85$ and $\beta = 1.90$
 $2V = 44^\circ$ For the density of a find use stuff Copper base 1000 for lead is 1000
 See Restricted and Limited Areas

[illegible]

LAUMONTITE *Leucanthide* *Crystals* 100-150 μ

Monoclinic Axes $a \cdot b \cdot c = 7.1457 \cdot 1.07606 \cdot 3 = 68^\circ 46'$

Twins, tw. pl. at 100. Common form: the prism $h = 110 \wedge 1,0 = 93^\circ 44'$, with oblique termination $c = 201 \wedge 001 \wedge 201 = 50^\circ 35'$; $\angle_{100} = 100^\circ 44'$, rather rare and divergent.

Cleaveage: $h_0(10)$ and $m_0(10)$ very perfect $n_0(10)$ in perfect. Fracture uneven. Not very brittle. $R = 3.5-4$ $G = 2.25-2.30$. Luster vitreous, reflecting to pearly upon the faces of cleavage. Color white, passing to yellow or gray, sometimes red. Striae uncolored. Transparent to translucent. Becoming opaculous usually in violet on exposure. Optically

Arch. 14. 6000. $A \cdot C \text{ axis} = +65^\circ$ $\epsilon = 70^\circ$ Despers. in large, $\rho < 1$,
incl. slight. $2V = 25^\circ$ $\sigma = 1.514$ $\rho = 1.524$ $\gamma = 1.525$

$$\text{Солно.} - (\text{Ca Na}_2 \text{ Al-Si}_3\text{O}_{10} \cdot 4\text{H}_2\text{O})$$
[illegible]

Pyru, etc. B.H. swells in am. when at 40° to a white mass. (4) In mass with hydrotic acid

Obs. In almost all occurs in the cavities of many rock types (e.g. basalt and andesite) eruptive rocks, also in the dyke and veins, as such it is seldomly given a separate name. In metamorphic rocks, gneiss, mica schist, clay slate, talc in marble etc. in veins, especially in coarse boulders.

[illegible]

In the United States in northeastern New Jersey at Bergen Hill, West Paterson, Great New Bay, and Great Bear Islands, Pennsylvania; also in Italy, France, the copperiferous schists of Hesse, and Michigan. In Nova Scotia at various localities, but not in the Bay of Fundy district.

Laubazite $(Ca, Na, Al_2Si_2O_7) \cdot 6H_2O$ rhomboh. $\pi = 4.5^\circ$, $\sigma = 20.5^\circ$. Fracture conchoidal. Lustre vitreous. $n_x = 1.47$, $n_y = 1.48$. Occurs upon phosphite in contact at Laubach, Sweden.

Chabazite Group. Rhombobedral

| | | π° | σ° |
|-----------|-------------------------------------|-------------|----------------------------------|
| Chabazite | $(Ca, Na, Al_2Si_2O_7) \cdot 6H_2O$ | 85° 14' | 10860 |
| Gmelinite | $(Na, Ca, Al_2Si_2O_7) \cdot 6H_2O$ | 68° 8' | 0.7345 or $\frac{1}{2}c = 11017$ |
| Levyne | $CaAl_2Si_2O_7 \cdot 5H_2O$ | 73° 56' | 0.8357 or $\frac{1}{2}c = 11143$ |

The Chabazite Group includes these three rhombobedral species. The fundamental rhombobedra have different angles σ , as shown in the axial ratios above; they are closely related, since, taking the rhombobedron of Chabazite as the basis, that of Gmelinite has the symbol 20.24 and of Levyne 30.54 . Because of optical evidence these minerals have been assumed to be triclinic or monoclinic and owe their hexagonal character to intimate twinning. The monocrystalline constants that have been derived on this assumption have close relations to those of the members of the Phillipsite Group.

The variation in composition often observed in the first two species has led to the adoption of a hypothesis that they are to be viewed as isomorphous mixtures of the feldspar-like compounds

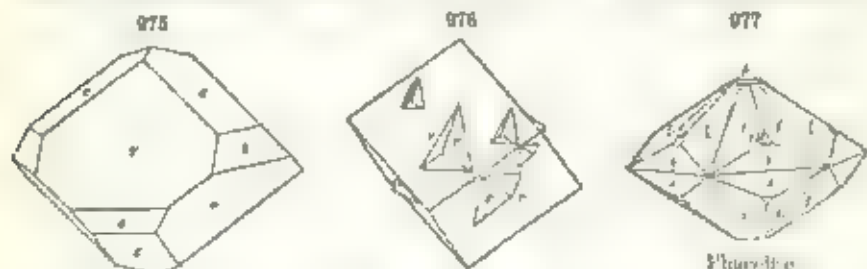


The exact formulas for these minerals are, however, still uncertain.

CHABAZITE.

Rhombobedral. Axis $c = 10860$ (9011 \wedge 1011 = $51^\circ 25'$)

Twins: (1) tw. axis c axis, penetration-twins common. (2) Tw. pi $r(1011)$, contact-twins, rare. Form commonly the simple rhombobedron



varying little in angle from a cube (π 1011 \wedge 1101 = $85^\circ 14'$), also r and $\pi(0112)$ ($\sigma' = 4^\circ 47'$). Also in complex shapes. Also isomorphous.

Fracture (1011) rather uneven. Fracture uneven. Break $\pi = 4.5$, $\sigma = 20.5$ 216. Luster vitreous, or white, flesh red, streak white. Color transparent to translucent. Optically -, uniax. (Andersberg, also haydenite). Birefringence low. The interference-figure usually confused, sometimes distinctly axial. Basal sections then divided into

sharply defined sectors with different optical orientation. These anomalous optical characters have been assumed to be due to the relative amounts of C₆ and Na₂ present, to the amount of water, etc. Mean refractive index 1.48.

[illegible]

Comp. — Somewhat uncertain since a rather wide variation is often noted even among specimens from the same locality. The composition usually corresponds to $(\text{Ca}, \text{Na})_2\text{Al}_2\text{Si}_2\text{O}_{10} \cdot 6\text{H}_2\text{O}$.

Polysyllables are treated in special chapters 440 sometimes, history and structure.

Pyr., etc. It is in masses in fused to a clear glass, nearly opaque. Decomposed by hydrofluoric acid, with evolution of a gas which

Did I inform you by e-mail about the new version of the software? It is harder than the old one, but it is more powerful. It is a change, but it is a change for the better.

Obs. Chlamyde occurs mostly in the amygdaloid cavities of basalt and rhyolite rocks, and occasionally in gneiss, syenite, mica-schist, hornblende, and granite. It is most common in the amygdaloid cavities of basalt, and is often associated with other minerals, such as quartz, calcite, and iron pyrites. In the amygdaloid cavities of basalt, it is often associated with iron pyrites, and is sometimes associated with calcite. In the amygdaloid cavities of rhyolite, it is often associated with iron pyrites, and is sometimes associated with calcite. In the amygdaloid cavities of gneiss, syenite, mica-schist, and granite, it is often associated with iron pyrites, and is sometimes associated with calcite.

In the United States of America, at West Potomac, and near where a car trip would
of the road to New Jersey, the following are the names, Maryland (Annapolis). In
Virginia at the city of Alexandria. In New Jersey, near of or (the latter being
Washington, D. C. In the United States of America, at the city of Washington, D. C.
Washington, D. C. In the United States of America, at the city of Washington, D. C.

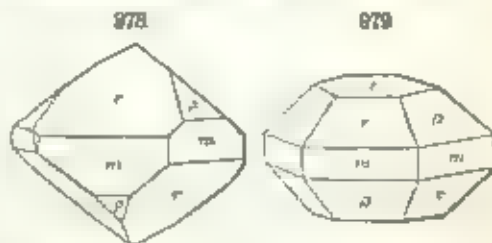
It is a matter of fact that the only person who has ever been in the place of a value.

GME1-INTT

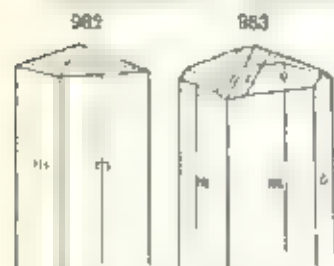
Rhombohedral. Axis $c = 0.7345$.

Crystals usually hexagonal in aspect, some ones prismatic and thin, and tabular rhombohedral, $10\bar{1}1 \wedge \bar{1}101 = 68^\circ 8'$, $10\bar{1}1 \wedge 01\bar{1}1 = 37^\circ 41'$.

Cleavage: $m(10\bar{1}0)$ easy;
 $c(0001)$ sometimes distinct. Fracture uneven. Brittle. $H = 4.5$. $G = 2.04-2.17$. Luster vitreous. Colorless-yellowish white, greenish white, red-
 ish-white (fleshy-red). Transparent to translucent. Optically positive, also
 negative. Birefringence very low. Interference-figure often disturbed, and



NATROLITE

Orthorhombic Axes $a : b : c = 0.9785 : 1 : 0.7536$ 

| | | |
|----|-----|----------------------|
| mm | 110 | $110 = 88^\circ 45'$ |
| mm | 111 | $111 = 81^\circ 1'$ |
| pc | 111 | $111 = 3^\circ 18'$ |
| pc | 111 | $111 = 38^\circ 47'$ |

Crystals prismatic usually very slender to tabular, frequently louvered or in acicular groups. Also fibrous, radiating, massive granular, or compact. Axes usually exhibiting a 1 or 2 plane cylindrical. There are eight molecules in the unit cell.

Calc. $a = 11.0$ perfect, $b = 0.10$ imperfect perhaps only a plane of parting. Fracture uneven. $H = 5.5$, $G = 2.25$ to 2.25 . Luster vitreous, sometimes pearly especially in fibrous variety. Color white or colorless to grayish, yellowish to red. Transparent to translucent. $D_{20} = 2.00$. Axes $a = b = 0.10$, $c = 0.01$. $2V = 63^\circ$, $\alpha = 1.480$, $\beta = 1.482$, $\gamma = 1.493$.

Var. *Orthorhombic*. Crystals either in a group of slender or in a massive granular variety. The former are usually prismatic or louvered, the latter are usually massive or granular. The former are usually colorless or white, the latter are usually grayish or yellowish. The former are usually transparent to translucent, the latter are usually opaque. The former are usually found in the same region as the latter. The latter are usually found in the same region as the former. The former are usually found in the same region as the latter. The latter are usually found in the same region as the former.

Amorphous. Specimens of this variety have been given to the name of *natrolite* where it is found in a massive granular form. It is usually colorless or white, and is usually transparent to translucent. It is usually found in the same region as the crystalline variety. It is usually found in the same region as the crystalline variety. It is usually found in the same region as the crystalline variety. It is usually found in the same region as the crystalline variety.

Comp. — $\text{Na}_2\text{A}(\text{Si}_2\text{O}_7 \cdot 2\text{H}_2\text{O})$ or $\text{Na}_2\text{A}(\text{Al}_2\text{O}_7 \cdot 3\text{SiO}_3 \cdot 2\text{H}_2\text{O}) = \text{SiO}_2 47.4$, alumina 20.8, Na_2O 16.4, water 9.5 = 100.

Pyx., etc. In the class, natrolite is a very common mineral. It is found in a variety of forms, and is usually colorless or white. It is usually transparent to translucent. It is usually found in the same region as the crystalline variety. It is usually found in the same region as the crystalline variety. It is usually found in the same region as the crystalline variety. It is usually found in the same region as the crystalline variety.

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In the United States, natrolite is found in the region of northeastern New Jersey, at Bergen Hill, near Paterson, Westborough, Connecticut, and at Mount Mansfield, Vermont. It is also found in the region of the Pacific Northwest, at Cape Mudge, British Columbia. Large crystals come from the Ice Harbor region of British Columbia.

[illegible]

SCOLLECTE

Mean $\Delta \ln \sigma_{\text{eff}} = 0.07 \pm 0.03$ (18)

These two phenomena suggest that $\text{H}_2\text{O} + \text{H}_2\text{O} = \text{H}_3\text{O}^+ + \text{OH}^-$ is a two-step reaction for $\text{H}_2\text{O} + \text{H}_2\text{O} \rightarrow \text{H}_3\text{O}^+ + \text{OH}^-$, suggesting that the first step is a proton transfer from H_2O to H_2O to form H_3O^+ and OH^- . This is also consistent with the fact that the first step is a proton transfer from H_2O to H_2O to form H_3O^+ and OH^- .

$\sigma = 1.512$, $\delta = 1.519$, $\gamma = 1.519$

Comp. $4 \times 10.8 + 4 \times 14 + 3 \times (2 \times 14 + 3 \times 16 + 3 \times 1) = 246.6$ g, and
 1 mole 246.6 g in 100 g water 13% = 100

$\frac{d}{dt} \left(\frac{\partial L}{\partial \dot{x}} \right) = \frac{\partial L}{\partial x}$

1. The first part of the document is a list of names and their corresponding dates of birth. The names are written in a cursive script, and the dates are in a standard font. The list is organized into two columns.

| Name | Date of Birth |
|-------------|---------------|
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| 140. [Name] | 2011 |
| 141. [Name] | 2012 |
| 142. [Name] | 201 |

(1) The first step is to identify the main components of the system. This involves understanding the hardware and software involved, and how they interact.

[illegible]

Medicate

$\frac{1}{2} \frac{d}{dt} \int_{\mathbb{R}^n} |u|^2 dx = \int_{\mathbb{R}^n} u \frac{du}{dt} dx = \int_{\mathbb{R}^n} u \left(-\frac{1}{2} \Delta u \right) dx = \frac{1}{2} \int_{\mathbb{R}^n} |\nabla u|^2 dx$

Figure 1. The effect of the concentration of the Ca^{2+} solution on the Ca^{2+} concentration in the Ca^{2+} solution. The Ca^{2+} concentration in the Ca^{2+} solution was 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0, 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7, 1.8, 1.9, 2.0, 2.1, 2.2, 2.3, 2.4, 2.5, 2.6, 2.7, 2.8, 2.9, 3.0, 3.1, 3.2, 3.3, 3.4, 3.5, 3.6, 3.7, 3.8, 3.9, 4.0, 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8, 4.9, 5.0, 5.1, 5.2, 5.3, 5.4, 5.5, 5.6, 5.7, 5.8, 5.9, 6.0, 6.1, 6.2, 6.3, 6.4, 6.5, 6.6, 6.7, 6.8, 6.9, 7.0, 7.1, 7.2, 7.3, 7.4, 7.5, 7.6, 7.7, 7.8, 7.9, 8.0, 8.1, 8.2, 8.3, 8.4, 8.5, 8.6, 8.7, 8.8, 8.9, 9.0, 9.1, 9.2, 9.3, 9.4, 9.5, 9.6, 9.7, 9.8, 9.9, 10.0, 10.1, 10.2, 10.3, 10.4, 10.5, 10.6, 10.7, 10.8, 10.9, 11.0, 11.1, 11.2, 11.3, 11.4, 11.5, 11.6, 11.7, 11.8, 11.9, 12.0, 12.1, 12.2, 12.3, 12.4, 12.5, 12.6, 12.7, 12.8, 12.9, 13.0, 13.1, 13.2, 13.3, 13.4, 13.5, 13.6, 13.7, 13.8, 13.9, 14.0, 14.1, 14.2, 14.3, 14.4, 14.5, 14.6, 14.7, 14.8, 14.9, 15.0, 15.1, 15.2, 15.3, 15.4, 15.5, 15.6, 15.7, 15.8, 15.9, 16.0, 16.1, 16.2, 16.3, 16.4, 16.5, 16.6, 16.7, 16.8, 16.9, 17.0, 17.1, 17.2, 17.3, 17.4, 17.5, 17.6, 17.7, 17.8, 17.9, 18.0, 18.1, 18.2, 18.3, 18.4, 18.5, 18.6, 18.7, 18.8, 18.9, 19.0, 19.1, 19.2, 19.3, 19.4, 19.5, 19.6, 19.7, 19.8, 19.9, 20.0, 20.1, 20.2, 20.3, 20.4, 20.5, 20.6, 20.7, 20.8, 20.9, 21.0, 21.1, 21.2, 21.3, 21.4, 21.5, 21.6, 21.7, 21.8, 21.9, 22.0, 22.1, 22.2, 22.3, 22.4, 22.5, 22.6, 22.7, 22.8, 22.9, 23.0, 23.1, 23.2, 23.3, 23.4, 23.5, 23.6, 23.7, 23.8, 23.9, 24.0, 24.1, 24.2, 24.3, 24.4, 24.5, 24.6, 24.7, 24.8, 24.9, 25.0, 25.1, 25.2, 25.3, 25.4, 25.5, 25.6, 25.7, 25.8, 25.9, 26.0, 26.1, 26.2, 26.3, 26.4, 26.5, 26.6, 26.7, 26.8, 26.9, 27.0, 27.1, 27.2, 27.3, 27.4, 27.5, 27.6, 27.7, 27.8, 27.9, 28.0, 28.1, 28.2, 28.3, 28.4, 28.5, 28.6, 28.7, 28.8, 28.9, 29.0, 29.1, 29.2, 29.3, 29.4, 29.5, 29.6, 29.7, 29.8, 29.9, 30.0, 30.1, 30.2, 30.3, 30.4, 30.5, 30.6, 30.7, 30.8, 30.9, 31.0, 31.1, 31.2, 31.3, 31.4, 31.5, 31.6, 31.7, 31.8, 31.9, 32.0, 32.1, 32.2, 32.3, 32.4, 32.5, 32.6, 32.7, 32.8, 32.9, 33.0, 33.1, 33.2, 33.3, 33.4, 33.5, 33.6, 33.7, 33.8, 33.9, 34.0, 34.1, 34.2, 34.3, 34.4, 34.5, 34.6, 34.7, 34.8, 34.9, 35.0, 35.1, 35.2, 35.3, 35.4, 35.5, 35.6, 35.7, 35.8, 35.9, 36.0, 36.1, 36.2, 36.3, 36.4, 36.5, 36.6, 36.7, 36.8, 36.9, 37.0, 37.1, 37.2, 37.3, 37.4, 37.5, 37.6, 37.7, 37.8, 37.9, 38.0, 38.1, 38.2, 38.3, 38.4, 38.5, 38.6, 38.7, 38.8, 38.9, 39.0, 39.1, 39.2, 39.3, 39.4, 39.5, 39.6, 39.7, 39.8, 39.9, 40.0, 40.1, 40.2, 40.3, 40.4, 40.5, 40.6, 40.7, 40.8, 40.9, 41.0, 41.1, 41.2, 41.3, 41.4, 41.5, 41.6, 41.7, 41.8, 41.9, 42.0, 42.1, 42.2, 42.3, 42.4, 42.5, 42.6, 42.7, 42.8, 42.9, 43.0, 43.1, 43.2, 43.3, 43.4, 43.5, 43.6, 43.7, 43.8, 43.9, 44.0, 44.1, 44.2, 44.3, 44.4, 44.5, 44.6, 44.7, 44.8, 44.9, 45.0, 45.1, 45.2, 45.3, 45.4, 45.5, 45.6, 45.7, 45.8, 45.9, 46.0, 46.1, 46.2, 46.3, 46.4, 46.5, 46.6, 46.7, 46.8, 46.9, 47.0, 47.1, 47.2, 47.3, 47.4, 47.5, 47.6, 47.7, 47.8, 47.9, 48.0, 48.1, 48.2, 48.3, 48.4, 48.5, 48.6, 48.7, 48.8, 48.9, 49.0, 49.1, 49.2, 49.3, 49.4, 49.5, 49.6, 49.7, 49.8, 49.9, 50.0, 50.1, 50.2, 50.3, 50.4, 50.5, 50.6, 50.7, 50.8, 50.9, 51.0, 51.1, 51.2, 51.3, 51.4, 51.5, 51.6, 51.7, 51.8, 51.9, 52.0, 52.1, 52.2, 52.3, 52.4, 52.5, 52.6, 52.7, 52.8, 52.9, 53.0, 53.1, 53.2, 53.3, 53.4, 53.5, 53.6, 53.7, 53.8, 53.9, 54.0, 54.1, 54.2, 54.3, 54.4, 54.5, 54.6, 54.7, 54.8, 54.9, 55.0, 55.1, 55.2, 55.3, 55.4, 55.5, 55.6, 55.7, 55.8, 55.9, 56.0, 56.1, 56.2, 56.3, 56.4, 56.5, 56.6, 56.7, 56.8, 56.9, 57.0, 57.1, 57.2, 57.3, 57.4, 57.5, 57.6, 57.7, 57.8, 57.9, 58.0, 58.1, 58.2, 58.3, 58.4, 58.5, 58.6, 58.7, 58.8, 58.9, 59.0, 59.1, 59.2, 59.3, 59.4, 59.5, 59.6, 59.7, 59.8, 59.9, 60.0, 60.1, 60.2, 60.3, 60.4, 60.5, 60.6, 60.7, 60.8, 60.9, 61.0, 61.1, 61.2, 61.3, 61.4, 61.5, 61.6, 61.7, 61.8, 61.9, 62.0, 62.1, 62.2, 62.3, 62.4, 62.5, 62.6, 62.7, 62.8, 62.9, 63.0, 63.1, 63.2, 63.3, 63.4, 63.5, 63.6, 63.7, 63.8, 63.9, 64.0, 64.1, 64.2, 64.3, 64.4, 64.5, 64.6, 64.7, 64.8, 64.9, 65.0, 65.1, 65.2, 65.3, 65.4, 65.5, 65.6, 65.7, 65.8, 65.9, 66.0, 66.1, 66.2, 66.3, 66.4, 66.5, 66.6, 66.7, 66.8, 66.9, 67.0, 67.1, 67.2, 67.3, 67.4, 67.5, 67.6, 67.7, 67.8, 67.9, 68.0, 68.1, 68.2, 68.3, 68.4

From the Faroe Islands

$\frac{d}{dt} \left(\frac{\partial L}{\partial \dot{x}} \right) = \frac{\partial L}{\partial x}$

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Fingerring Der Ring, den ein Edelstein umschließt. Der Ring, den ein Edelstein umschließt, ist ein Ring, der aus einem Metall besteht, das in einem Ring geformt ist. Der Ring, den ein Edelstein umschließt, ist ein Ring, der aus einem Metall besteht, das in einem Ring geformt ist.

1. The first part of the paper is devoted to the study of the properties of the function $f(x)$ defined by the equation $f(x) = \sum_{n=0}^{\infty} a_n x^n$, where $a_n = \frac{1}{n!}$. It is shown that $f(x)$ is an entire function and that its Taylor series converges for all x . The function $f(x)$ is also shown to be a solution of the differential equation $y' = y$.

[illegible]

(010). $Z = b$ axis. X A a axis $= 2l$. $\alpha = 1.576$, $\beta = 1.570$, $\gamma = 1.563$. Occurs in pegmatite masses in the granite of Bayes, Lago Maggiore, Piedmont, Italy.

Baryte. BaSO_4 . A tetragonal crystal and a rhombohedron with a cleavage of the rhombohedron. Pseudo hexagonal. In thin tetragonal plates which in polarized light show division into six zones and one cleavage parallel to base. $H = 5.5$, $G = 3.0$. Easily fusible. Hygroscopic. X Z cleavage. $d = 4.65$. 25 small. Found as crystal crusts in pegmatite veins at Mahabuta, on Mt. Baly, Madagascar.

Hornblende. $\text{Si}_2\text{Al}_2\text{O}_{10}(\text{OH})_2 \cdot 3\text{H}_2\text{O}$. Monoclinic, radiated. $H = 4.5-5$, $G = 2.2-2.5$. Color white, also dark gray. Index 40. From Litchfield, Kearsarge Co., Maine, and howeite or to a mixture of anthophyllite, by rangite and howite. Howite from the Litchfield, Maine, is similar.

Dacrydite. $\text{Na}_2\text{Si}_2\text{O}_7 \cdot 2\text{H}_2\text{O}$. Monoclinic. Occurring in small eight-sided prismatic tabular crystals, composed of eight sectors. Twinning rare. $H = 1.0$. Pseudo hexagonal. (100) . $H = 4.4-5$, $G = 2.10$. B.B. decomposes, effloresces and fuses to a white enamel. Decomposed by HCl . Transparent colorless. Optically $+$. Ax in $+$ (010) . $X = b$ axis. Z c axis $= 36$. $2d = 6.0$. $\alpha = 1.492$, $\beta = 1.466$, $\gamma = 1.500$. Found in granite pegmatite at San Piero in Campo, Italy.

II. Mica Division

The species embraced under this Division fall into three groups: 1, the *Mica Group* including the *Micas* proper, 2, the *Chlorite Group*, or the *Brilliant Micas*, 3, the *Claylike Group*. Supplementary to these are the *Vermiculites*, hydrated compounds, chiefly results of the alteration of some one of the micas.

All of the above species have the characteristic micaceous structure, that is they have highly perfect basal cleavage and yield easily thin laminae. They belong to the monoclinic system but the position of the bisectrix in general deviates but little from the normal to the plane of cleavage—all of them show on the basal section plane angles of 60° or 120° , marking the relative position of the chief zones of forms present, and giving them the appearance of hexagonal or rhombohedral symmetry. Further, they are more or less closely related among themselves in the angles of prominent forms.

The species of this Division all yield water upon ignition, the micas mostly from 4 to 5 per cent, the chlorites from 10 to 13 per cent, this is probably to be regarded in all cases as water of constitution, and hence they are not properly *hydrated silicates*.

More or less closely related to these species are those of the *Serpentine* and *Talc* Division and the *Kaolin* Division, many of which show distinctly a mica-like structure and cleavage and also pseudo-hexagonal symmetry.

1. Mica Group. Monoclinic

| | | |
|---------------------|---------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Muscovite | Potassium Mica | $\text{H}_2\text{KAl}_2(\text{SiO}_3)_2$
$a \cdot b \cdot c = 0.57735 : 1 : 3.3128$ $\beta = 89^\circ 54'$ |
| Paragonite | Sodium Mica | $\text{H}_2\text{NaAl}_2(\text{SiO}_3)_2$ |
| Lepidolite | Lithium Mica | $(\text{OH}, \text{F})_2\text{KLiAl}_2\text{Si}_2\text{O}_{10}$ in part |
| Zinnwaldite | Lithium-iron Mica | |
| Biotite | Magnesium-iron Mica | $\text{H}_2\text{K}(\text{Mg}, \text{Fe})_2(\text{Al}, \text{Fe})(\text{SiO}_3)_2$ in part
$a \cdot b \cdot c = 0.57735 : 1 : 3.2473$ $\beta = 90^\circ 0'$ |
| Phlogopite | Magnesium Mica, usually containing fluorine, nearly free from iron. | $\text{H}_2\text{K}(\text{Mg}, \text{Al})(\text{SiO}_3)_2$ |
| Lepidomelane | Iron Mica. Contain ferric iron in large amount. | Annite. |

aluminum. On the basis of these observations, Pauling writes the following formulae:

| | |
|--------------|--------------------------------------------------------------------------|
| Talc | $(\text{OH})_2\text{Mg}_3(\text{Si}_4\text{O}_{10})$ |
| Pyrophyllite | $(\text{OH})_2\text{Al}_3(\text{Si}_4\text{O}_{10})$ |
| Phlogopite | $(\text{OH})_2\text{K}(\text{Mg}_3/\text{Al}_2\text{Si}_4\text{O}_{10})$ |
| Muscovite | $(\text{OH})_2\text{KAl}_2(\text{AlSi}_3\text{O}_{10})$ |
| Margarite | $(\text{OH})_2\text{Ca}_2\text{Al}_2(\text{AlSi}_3\text{O}_{10})$ |

Chemically considered, the micas are silicates, and in most cases orthosilicates, of aluminum with potassium and hydrogen, also often magnesium, ferrous iron, and in certain cases ferric iron, sodium, lithium (rarely rubidium and cesium), further, rarely barium, manganese, chromium. Fluorine is prominent in some species, and titanium is also sometimes present. Other elements (boron, etc.) may be present in traces. All micas react with water upon ignition—a consequence of the hydrogen (or hydroxyl) which they contain. The precise formulae to be given the different species and their isomorphous relations with each other, although they have been the subject of much study, must still be considered as uncertain.

MUSCOVITE. Common Mica. Potash Mica.

Monoclinic. Axes $a, b, c = 0.57735 : 1 : 3.128$ $\beta = 89^\circ 54'$

Twins common according to the *meridian law*; plates in the zone cM (011 \wedge 221 normal to c (001), the crystals often united by c . Crystals rhombic or hexagonal in outline with plane angles of 60° or 120° . Habit tabular, passing into tapering forms with planes more or less rough and strongly striated, sometimes with small forms common. Plates often very small and aggregated in scale, pin-point, or globular forms, or in scales and sandy masses, also cryptocrystalline and compact massive. For structure, see above.

Cleavage basal eminent. Also plates of secondary cleavage as shown in the pers. s. s. figure (see pp. 658 and 211), natural plates hence often well

| |
|----------------------------------------------|
| cM , 001 \wedge 221 = $85^\circ 30'$ |
| cP , 001 \wedge 111 = $8^\circ 39'$ |
| $M'M'$, 221 \wedge 231 = $31^\circ 14'$ |
| $M''M''$, 111 \wedge 111 = $50^\circ 10'$ |

narrow strips or thin fibers.

axis b , and less distinct in directions inclined 60° to

this. Thin, annular flexible and elastic when bent, very tough, harsh to the touch, passing in c axis which are less elastic and have a more or less waxy or talc-like feel. Etching-figures on c (001), monoclinic in symmetry (Fig. 521, p. 212).

$H = 2.22$, $G = 2.76-3$. Luster vitreous to more or less pearly or silky. Colorless, gray, brown, buff-brown, pale green, and violet, yellow, dark olive-green, rarely rose-red. Streak uncolored. Transparent to translucent.

Pleochroism usually feeble, distinct in some deep-colored varieties (see beyond). Absorption in the direction normal to the cleavage plane (direction $Y-Z$) strong, much stronger than transversely (direction X). Hence a crystal unless thin is nearly or quite opaque in the first case or though transparent through the prism. Optically — $Ax \parallel c$, b (0,0) and nearly



$\perp c(001)$. X inclined about -1° (behind) to a normal to $c(001)$. Dispersion $\rho > \nu$. $2V$ variable usually about 40° but diminishing in kinds of pegmatite relatively high in silica. $\alpha = 1.552$ $\beta = 1.562$ $\gamma = 1.588$. Indices variable, increasing with the amount of iron present.

Var. 1 Ordinary Muscovite. In crystals as above described often tabular $\perp c(001)$, also tapering with vertical faces rough and striated. The basal faces often rough unless as described by cleavage. More commonly in plates without distinct outlines, except as described in pegmatite as above. Lustrous in thin films very slight but passing in thin scales arranged in groups or other forms. In normal muscovite the thin laminae spring back with a resistance, but the scales are more or less harsh to the touch, almost very smooth, and a pearl-like luster in some specimens.

2 Damourite. In pegmatite magnesian gabbroite, hydro-muscovite, and most muscovites in granites. Lustrous sheet. Luster rather in pearls or silky and feel sometimes like talc. The scales are usually small and the plates are broken when they are free away from the surface and finally into the small crystals remaining like rounded concretions including small plates. These are covered by a thin, colorless, transparent, somewhat elastic film. Although often spoken of as hydro-muscovite, it has a composition intermediate and the scales vary as necessary. Contains more water than ordinary muscovite, they may, however, give it off more readily.

Muscovite, as originally named, was the talc-like mass of Mt. Grenier by the Zellerbach, Tyrol, a talc-like granular to silky in texture, having nearly colorless white to colorless to pinkish white, crystals from the same as talc. It is a fine earthy muscovite and is a common aggregate and characterized by its silky luster. Hence the name from *musca*, fly. It is a low temperature mineral.

Comp. For the most part an orthosilicate of aluminum and potassium $H_2K_2Al_2Si_2O_{10}$. If as in the common kinds $H_2K_2O = 2$, this becomes $H_2K_2Al_2Si_2O_{10} = 2H_2O \cdot K_2O \cdot 3Al_2O_3 \cdot 6SiO_2 = SiO_2 \cdot 45$, 2 , alumina 35 , 3 , potash 11.8 , water $4.5 = 100$.

Some kinds give a larger amount of silica 47 to 49 per cent than corresponds to a normal orthosilicate and they have been called phengite.

Iron is also present in small amounts. In some cases iron present as a silicate $Fe = 2$ to 2.5 . Potassium is also present, a fact from Schwartzbach, Zellerbach, Tyrol and elsewhere.

Pyrrh. In the closed tube gives water. If B whitens and fuses on the thin edge $CF = 1.7$ to a gray or yellow glass. With fluxes gives red color for iron and some other minerals such as chromium. Not decomposed by acids. Decomposed on fusion with alkali to carbonates.

Dif. Distinguished in normal kinds from talc by the species of this division is the perfect basal cleavage and the perfect structure, the pale color separates it from most of the minerals more like talc than those of phengite and also more than those of the little mica and the chlorites.

Micro. In thin sections recognized by want of color and by the perfect cleavage shows a fine lamellar structure. $1000 \times$ shows a 2×100 μ in a direction inclined to c . By collector light and on microscope the same sections show a peculiar wavy surface with satiny luster, lustrous rather than with interference colors bright. These changes in color and luster are due to the absorption of certain refractive minerals due to the effect of light rays given off by the refractive minerals.

Obs. Muscovite is the most common mineral in rocks. It is an essential constituent of the many crystals in rocks that are rich in potash and alumina, being that silicate which is the most abundant in granitic pegmatites. It also in some systems, especially in granites, and their pegmatites, is found in the volcanic rocks in large amounts, appearing often as a secondary product. It is an essential constituent of the many silicates, phengite and related rocks where it is metamorphosed with talc. The variation with other talc-like forms, like pearl, or silky luster are characteristic of much mica. Hydro-muscovite, which has often been erroneously called muscovite. It occurs in granites and may occur in the contact zones of granitic rocks, or in some igneous rocks, or in some metamorphic rocks etc. The largest crystals are found in some granites in the contact zones in granites and especially in the pegmatites which appear with granitic intrusions, often in small veins, or in the granite or in its vicinity. Often in such occurrences muscovite appears in enormous plates

pink tourmaline, of which it appears to be an alteration product. Occurs with tourmaline and biotite in Oxford Co., Maine, at Hesper Mt. Mica near Paris, and at Buckfield. In Connecticut in Middlesex Co., at Haddam Neck.

Zinnwaldite.—An iron-lithium mica of iron near biotite. See further under lepidolite above. Color pale violet, passes to brown and dark gray. Optically— $X \wedge c$ axis = $0^\circ 47'$, $Y = 155^\circ$. Zinnwaldite is most commonly a secondary mineral occurring in the cassiterite- and topaz-bearing pegmatites of the Erzgebirge. Found in the Erzgebirge of Saxony, at Zinnwald, Altenberg, etc. in connection with tin veins, as a part of the wall, at St. Lue, and elsewhere. From Narsarsuaq, Greenland. In Alaska from the York district on Seward Peninsula.

Crocidolite is a related lithium mica from the granite of Rockport in Cape Ann, Essex Co., Massachusetts, which is due in composition to Fe^{2+} and Fe^{3+} ions from Karsgöf in the Langesund strait, Greenland. *Tringite* is a mica which contains little lithium in pegmatite veins near Wausau, Marathon Co., Wisconsin.

Manandowite.—A basic ferro-silicate of lithium and manganese, $\text{H}_2\text{Li}_2\text{Al}_2\text{B}_2\text{Si}_2\text{O}_{12}$. Orthorhombic? Pseudohexagonal. Muscovitic. In lamellar aggregates or pseudohexagonal crystals of hexagonal pattern. Perfect basal cleavage. $G = 2.85$. Luster vitreous to resinous. Color white. Luster pearly. Optically— $Z \perp$ to cleavage. $\beta = 1.6$. Axial angle small and variable. Found in pegmatite at Antandrokondy, near Mt. Dity on the Manandow River, Madagascar.

BIOTITE.

Monoclinic, pseudo-rhombic-hedral. Axes $a, b; c = 0.57735; 1: 3.2743$, $\beta = 90^\circ$.

Habit tabular or short prismatic, the pyramidal faces often repeated in oscillatory combination. Crystals often apparently rhombohedral in symmetry since $r(101)$ and $s(132)$, $c(132)$, which are inclined to $c(001)$ at sensibly the same angle, often occur together. Further, the zones to which these faces belong are inclined 120° to each other, hence the hexagonal outline of basal sections. Twins, according to the mica law (tw. pl. \perp zone in the prismatic zone $\perp c(001)$). Often in disseminated scales, sometimes in massive aggregations of cleavable scales.

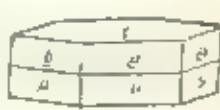
$$\begin{array}{l} m, 001 \wedge 112 = 73^\circ 4' \\ cM, 001 \wedge 221 = 85^\circ 38' \\ cM, 001 \wedge 111 = 81^\circ 19' \end{array}$$

$$\begin{array}{l} cr, 001 \wedge 101 = 80^\circ 0' \\ c, 001 \wedge 112 = 84^\circ 0' \\ MM, 221 \wedge 221 = 59^\circ 48' \end{array}$$

987

988

989



Cleavage—basal, highly perfect—planes of separation shown in the projection-figure; also gliding-planes $\rho(205)$, $\gamma(135)$ shown in the pressure-figure inclined about 66° to $c(001)$ and yielding pseudo-crystalline forms (Fig. 545, p. 210). $H = 2.5-3$, $G = 2.7-3.1$. Luster subresinous and more or less pearly on a cleavage surface, and sometimes submetallic when black, lateral surfaces vitreous when smooth and shining. Colors usually green to black, often deep black in thick crystals, and sometimes even in thin laminae unless the laminae are very thin, such thin laminae green, blood-red, or brown by transmitted light, also pale yellow to dark brown, rarely white. Streak uncolored. Transparent to opaque.

Pleochroism strong. $Y = Z =$ dark brown, reddish brown, green. $X =$

Pleochroism: strong Z yellow-green, Y indigo-blue X olive-green. Optically +. Ax pl nearly 0.010. Z inclined about 12° or more to the normal to (001). Dispersion $\mu > \nu$, large, also horizontal. $2V = 36$ to 60° . $d = 1.72$. Birefringence low, $\gamma - \alpha = 0.004$, (0116).

Comp. For the typical $H_2FeMgAs_2O_8$. If iron alone is present, this requires silica 23.5, alumina 40.5, iron peroxide 28.5, water 7.2 = 100.

The division into varieties has been made on the following basis: Chloroid $H_2FeAs_2O_8$, $H_2FeMgAs_2O_8$, $H_2FeMg_2As_2O_8$, $H_2FeMg_3As_2O_8$.

Macro. Having seen in this section by the metal outcrops and general microscopic appearance that the green color is due to iron alone, the next step is to determine the nature of the iron. The iron is present in the form of iron pyrites, and the nature of the iron is determined by the nature of the iron pyrites.

Obs. The crystals are colorless, transparent, and have a glassy luster. They are often found in small groups, and the crystals are often found in small groups, and the crystals are often found in small groups.

The typical chloroid from the iron and iron pyrites is the iron pyrites. The iron pyrites is the iron pyrites, and the iron pyrites is the iron pyrites. The iron pyrites is the iron pyrites, and the iron pyrites is the iron pyrites. The iron pyrites is the iron pyrites, and the iron pyrites is the iron pyrites.

3. Chlorite Group. Monoclinic

The Chlorite Group takes its name from the fact that a large part of the minerals in the group are chlorite, and the green color is due to iron alone. The minerals in the group are chlorite, and the green color is due to iron alone. The minerals in the group are chlorite, and the green color is due to iron alone. The minerals in the group are chlorite, and the green color is due to iron alone.

Chlorite is a mineral which is found in the form of iron pyrites, and the iron pyrites is the iron pyrites. The iron pyrites is the iron pyrites, and the iron pyrites is the iron pyrites. The iron pyrites is the iron pyrites, and the iron pyrites is the iron pyrites. The iron pyrites is the iron pyrites, and the iron pyrites is the iron pyrites.

of these molecules ferrous iron may replace magnesium, and in the latter ferric iron (or chromium) may replace aluminum. On this basis the following classification of the orthochlorites has been made.

Penninite = $H_2Mg_2Si_2O_6 > H_2Mg_2Al-Si_2O_6$

Chloritoid = $1H_2Mg_2Si_2O_6, 1H_2Mg_2Al_2Si_2O_6$

Prochlorite = $H_2Mg_2Si_2O_6 < H_2Mg_2Al_2Si_2O_6$

The "leptochlorites" are more complicated in composition, have a higher iron-content, less water, and approach more nearly the composition of the "brittle rocks." They commonly have higher refractive indices than the orthochlorites, and are in general optically negative and almost uniaxial in character. They commonly occur as sandy, lense, or earthy aggregates in rocks.

The only distinctly crystallized species of the Chlorite Group are chloritoid and penninite. These have similar compositions, but while the former is monoclinal in form and habit, the latter is pseudorhombic-hedral and usually uniaxial. Prochlorite (including some ripidolite and corundophite also) occur in distinct cleavage masses.

Besides the species named there are other kinds less distinct in form, occurring in series, also fibrous to massive or earthy. They are most of them of less importance in composition, but in many cases because of their extensive occurrence, of considerable geological importance. These latter forms occur as secondary minerals resulting from the alteration especially of ferrous green silicates, such as talc, pyroxene, diopside, also garnet, vesuvianite, etc. They are often accompanied by other secondary minerals, as serpentines, limonite, calcite, etc., especially in the altered forms of igneous rocks.

The rock-making chlorites are recognized in thin sections by their characteristic appearance in thin leaves, scales or fibres, some having aggregated in aggregates, by their greenish color, pleochroism, extinction parallel to the cleavage (in the cleavage and not at right angles), low relief and extremely low interference colors, which thus are excepted to be "driftnite" by the other chlorites, and they are readily distinguished from the micas, with which they strongly resemble and with which they are frequently associated.

PENNINITE. Pennine.

Apparently rhombohedral in form but strictly pseudorhombic-hedral and monoclinic.

Habit rhombohedral, sometimes thick tabular with a well pronounced again steep rhombohedral also in aperting six-sided pyramids. Reticular faces often continuously striated. Lustrous, transparent with a pearly color, contact-sides also green, by a thin, here corresponding faces filled with in position. 2-mil. size, 10-15-20 mil. in, 10-20 mil. x 112 (crystals often in cross groups). Aggregate, consisting of an aggregation of scales; also compact crystalline cleavage and highly perfect.



Laminae flexible. Pseudomonoclinic and pseudorhombic figure as with chloritoid but less easy to obtain in cleavage.

$H = 2.25$, $G = 2.6-2.55$. Luster of cleavage-surface pearly if internal

plates vitreous, and sometimes brilliant. Color emerald- to olive-green; also violet pink rose-red, grayish red occasionally yellowish and silver-white. Transparent to subtranslucent. Pleochroism distinct usually in axial green \pm yellow. Opacities $+$ also $-$, and some may both in adjacent laminae of the same crystal. Usually sensibly uniaxial but sometimes distinctly biaxial, and both in the same section. Sometimes a uniaxial mineral when the border is biaxial with $2L = 30^\circ$, the latter probably to be referred to clinocllore. $Ax \perp (010)$ $Bx \perp (001)$ $\beta = 1.576-1.60$

Var. 1 Penninite as first named, included a green crystalline chlorite from the Pennine Alps.

A. penninensis In hexagonal form bounded by steep beveled pyramids. Color somewhat greenish olive-red. Pleochroism distinct. Optically - from Lake Titicaca. Axial angle $2L = 30^\circ$. From Tarn Penninensis. Uniaxial or biaxial with axial angle $2L = 30^\circ$. *Geological* from Texas, Pennsylvania, and Rhode Island. From Lake Titicaca and Argentina.

Penninite is compact massive, without cleavage, and resembles serpentine.

Comp. Essentially the same as for clinocllore, $Fl_2(Mg, Fe)_2Al_2Si_2O_{10}$. See further on p. 669.

Pyrr., etc. In heated it yields water. If B. oxidation somewhat and is difficult to fuse. With the fluxes will melt to a glass, and for iron and steel is often used as a chlorite. Partly decomposed by hydrofluoric acid completely by aq. hydrochloric.

Micro. In thin sections shows poor green color and pleochroism usually mostly uniaxial.

Occ. To be found in chlorite and also crystalline schists. Occurs in Valais, Switzerland, where it is named in the region of Zillertal. In a few cases sometimes a few long thin needles have been found in the form of a few crystals in the Valais and in the region of the Zillertal. In the green schists it is found in the form of a few crystals in the Zillertal. In the green schists it is found in the form of a few crystals in the Zillertal. In the green schists it is found in the form of a few crystals in the Zillertal.

A. penninensis is found at the locality already mentioned and in large crystals from the region of the Zillertal. It is also found in the form of a few crystals in the Zillertal. In the green schists it is found in the form of a few crystals in the Zillertal. In the green schists it is found in the form of a few crystals in the Zillertal.

CLINOCHLORRE. *Rupicola* in part.

Mineral. Axes $a : b : c = 0.57735 : 1 : 2.2772$ $\beta = 80^\circ 40'$

(Crystals usually hexagonal in form, often tabular $c(001)$). Plane angles of the faces are 120° or 120° , and since closely similar angles are found in the crystals which are separated by 10° , the symmetry approximates to that of the rhombohedral system.

993



Pflanz

994



Schwarzenstein

995



Zillertal

Twins. As with penninite, see Figs 991, 992. Massive, coarse scaly granular to fine granular and earthy.

Cleavage $c(001)$ highly perfect. Laminae flexible tough, and but slightly elastic. Percussion- and pressure-figures orientated as with the mica (p. 658).

times red. Streak unicoloral or greenish. Laminae flexible, not elastic. Pencil raspy, does not cleave. Fracture + surface. L only slightly inclined to the normal to (001). Axial angle small, often nearly uniaxial again $2\epsilon = 45^\circ$. Dispersion $\rho < \omega$. Indices, 1.55-1.67.

Comp. — lower than in chalcocite and with ferrous iron usually but not always, in large amount. See farther on p. 669.

Obs. The very strong of double refraction is due to three crystal minerals in chalcite before it is broken up. The crystals are small, often in groups etc. The crystals are small, often in groups etc. The crystals are small, often in groups etc.

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Microscopic examination has established the fact that argentine in rock masses has been formed in a regular and systematic manner. It is found in the form of small, prismatic crystals, which are often aggregated into larger masses. The crystals are commonly shows a sharp cleavage, and the nature of the original material has been preserved. (Fig. 988, a, b, c (Pirsson).

Comp. — A magnesium silicate $\text{H}(\text{Mg}_2\text{Si}_2\text{O}_6)$ or $3\text{Mg}(\text{SiO}_3) \cdot 2\text{H}_2\text{O} = \text{Silica } 44.1$ magnesia 45.0, water 12.9 = 100. This product is often replaced in part by the magnesian silicate in small amount is sometimes present. The water is chiefly expelled at a red heat.

It is often related to the minerals of the Chlorite Group, see p. 684.

Prp., etc. — It is a dark green to black mineral, which is often found in the form of small, prismatic crystals. It is often found in the form of small, prismatic crystals, which are often aggregated into larger masses.

Dif. — It is often found in the form of small, prismatic crystals, which are often aggregated into larger masses. It is often found in the form of small, prismatic crystals, which are often aggregated into larger masses.

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Micro. — It is often found in the form of small, prismatic crystals, which are often aggregated into larger masses. It is often found in the form of small, prismatic crystals, which are often aggregated into larger masses.

and in Hesse, Germany, in Ontario, Canada, at Templeton. The silicates of the feldspar group are also found in the same region in the same country.

The silicates of the feldspar group are also found in the same region in the same country. The silicates of the feldspar group are also found in the same region in the same country. The silicates of the feldspar group are also found in the same region in the same country.

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Deweyite $\text{Na}_2\text{Si}_2\text{O}_6$ is a silicate of the soda group, but with more water. It is a perthite-like mineral. It is found in the same region in the same country. The silicates of the feldspar group are also found in the same region in the same country. The silicates of the feldspar group are also found in the same region in the same country.

Genthite $\text{Na}_2\text{Si}_2\text{O}_6$ is a silicate with part of the soda group. It is found in the same region in the same country. The silicates of the feldspar group are also found in the same region in the same country. The silicates of the feldspar group are also found in the same region in the same country.

Neptunite $\text{Na}_2\text{Si}_2\text{O}_6$ is an important type of silicate, containing more water than the others. It is found in the same region in the same country. The silicates of the feldspar group are also found in the same region in the same country. The silicates of the feldspar group are also found in the same region in the same country.

Neptunite $\text{Na}_2\text{Si}_2\text{O}_6$ is a silicate of the soda group. It is found in the same region in the same country. The silicates of the feldspar group are also found in the same region in the same country. The silicates of the feldspar group are also found in the same region in the same country.

Connellite $\text{Na}_2\text{Si}_2\text{O}_6$ is a silicate of the soda group. It is found in the same region in the same country. The silicates of the feldspar group are also found in the same region in the same country. The silicates of the feldspar group are also found in the same region in the same country.

Muscovite $\text{H}_4\text{Si}_2\text{O}_5$ is a silicate of the soda group. It is found in the same region in the same country. The silicates of the feldspar group are also found in the same region in the same country. The silicates of the feldspar group are also found in the same region in the same country.

TALC

Orthorhombic or monoclinic. Rarely in tabular crystals hexagonal or rhombohedral. prismatic angles of 90°. Usually in small, dense, nodular, granular and compact groups, also granular, massive, coarse or fine fibrous (pencil-morphous), also compact or cryptocrystalline.

Streak bluish white, perfect. Sects. Fibrous in thin laminae, but not elastic. Pencil-like groups in massive, also in the nodules. Luster greasy. $H = 1-1.5$ $G = 27-28$. Luster partly on cleavage surface. Color

Harmon is in from 2000, 2001, and 2002 (containing from 2000 to 2002).

LABRILLATE Compositae, perhaps *Mad. Mal.* 22, 5110. In snow-white fibrous tufts, $\frac{1}{2}$ - 1". In France from the north coast of Newfoundland on Montserrat in Ha. & Low and at Cap Pr. near Argentia. *Det. P. B. Robinson.*

[illegible]

Canadianite A variety of green, translucent to opaque, fibrous mineral, found in the green schists of the Canadian Shield, particularly in the area of the Canadian Shield near Verona, Ontario.

Granite (1) is a fine-grained, medium to coarse-grained, crystalline, light-colored, massive, and slightly foliated rock. It is composed of quartz, feldspar, and mica. The rock is hard and resistant to weathering. It is a common rock type in the area.

[illegible][illegible]

IV. KAOLIN DIVISION

KAOLIN MINERALS KAOLINITE, HACRITE, DICKITE

Mosaiclike in thin rhombohedral or hexagonal scales or plates with angles of 60° and 120°. Usually constituting a clay-like mass, either compact, friable or mealy.

Flavor: basal perfect. Flexible indurata. H = 2.25. G = 2.6-2.8. Luster of plates early of mass poorly dull earthy. Color white grayish white yellowish, sometimes brownish, brown or reddish. Season translucent to translucent usually not transparent and solid.

This is a study of minerals commonly to be found in the granite of Keshin shows three species with different optical characters. The suggested separation is into *variete* from near Fresting Saxony, *diacrite* from island of Anglessey, Wales, and the Moroccan variety *variete* 1 and *variete* 2. *Variete* 1 and *diacrite* are monoclinic. Optical characters: *Variete* 1 $\alpha = 1.501$ and $\beta = 1.507$. Indices $\alpha = 1.507$, 1.501 and $\beta = 1.502$, 1.501 , $\gamma = 1.505$, 1.505 . *Variete* and *diacrite* are nearly or quite transparent and the almost crystalline. *Variete* is transparent to opaque and nearly or completely parallel to c axis. *Variete* is usually optically \pm , rarely \pm to \pm to \pm , \pm to \pm . $Z = 0.005$ and three. The angle between λ and \pm is equal to $100^\circ = 10^\circ$ to 12° in *variete*, 15° to 20° in *diacrite*, 1° to 34° in *variete*. Dispersion $p > v$ rarely $p < v$ in *variete*, $p < v$ in *diacrite*, $p > v$ in *variete*. *Variete* absorbs very readily becoming pinkish, the other two do not show this. Study by X-rays shows distinctly different molecular structures in the three cases.

Ver. 1. *Kankinle Nante* *Enchite* is crystalline scales pure white and with a satin lustre; the above is the same as the above but with a satin lustre and a pinkish tint occurring in patches; a pinkish tint is also seen in the above but is not so marked as in the above.

Comp. — $\text{H}_2\text{Al}_2\text{Si}_2\text{O}_8$ or $2\text{H}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$ = silica 46.5, alumina 39.5, water 14.0 = 100. The water goes off at a high temperature, above 380°.

Pyrr. etc. Soluble in water. B.P. 113°C. at 760 mm. (45°C. at 10 mm.) Boils in contact with water.

Does infuencial earth, but readi

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in its occurrence and

1. The first step is to identify the problem or question that needs to be answered. This involves understanding the context and the specific requirements of the task.

7. How much of the total cost of the project is covered by the government?

[illegible]

The original was [redacted] by [redacted].

$\frac{1}{2} \left(\frac{1}{2} + \frac{1}{2} \right) = \frac{1}{2}$

... ..

1957 年 11 月 15 日 星期一

[illegible]

For the purpose of this study, the following hypotheses were formulated:

HYDROUS ALUMINUM SILICATES

HALLOYSITE

Massive. Clay-like or earthy.

For somewhat purity or waxy touch. Color white grayish greenish yellow.

Montmorillonite.— Perhaps $MgCaAl_2(Si_4Al_2O_{20} \cdot nH_2O)$ with $n = 5-7$. Massive clay to show the X-ray pattern of kaolinite and may be composed of that mineral and existing common particles within the structure. Very soft and tender. $d = 2$ —muscovite. Color white or gray at to rose-red and bluish also from manganese. Lustre, pearly. $n = 1.54-1.56$. A weak alteration product of silicate minerals. Found near Maricao-Mesa not far from Maguay Lagoon, San Juan, P.R. in. In France in Montmorillon, a soft brown colorate. Occurs there also in the Charente also from Saint-Jean-Pied-de-nez near Bayonne. Occurs also at a spring in the center of P. R. in a large. From the beach of St. Johns, Maryland, and from the Cape of Maryland. Also from Ireland, etc.

[illegible][illegible]

PYROPHYLLITE

Orthorhombic. Foliated radiated lamellar or somewhat fibrous also granular to compact or cryptocrystalline; the latter sometimes also

$H = 1.2$ $C = 24.29$ Luster of *testa* pearls of massive kind, dull and glistering. Color white, apple-green, grayish and brownish green, yellowish to ochre-yellow, grayish white. So transparent to opaque. Op. rarely.

[illegible]

Camp. $\text{H}_2\text{Al}_2\text{Si}_2\text{O}_7$, or $\text{H}_2\text{O Al}_2\text{O}_3 \cdot 48\text{SiO}_2$ = Silica 66.7, alumina 28.3,
water 5.0 = 100

Pyrr. etc. Yields water but only at a high temperature. R.B. whorls, and inner with affinity up the cone. The polished varieties are of a fine-lustered, smooth to touch. Using the fine variety of the above. Mounted with cedar oil and heated given a deep blue color. Partially decomposed by sulphuric acid, and even after a short time with addition of a catalyst.

It is noticeable that, for distinguishing by the reaction for aldehydes with chromic

Obs. Compact granite lies in the material or base of some of the rocks. The
 noted area is of the granite of the ...
 between ...
 the region ...
 large ...
 was of ...
 Bed ...

[illegible]

Use. - For the water treatment as well as for the

ALLOPHANE.

Amorphous. In incrustations, usually thin, with a mammillary surface, and resembling hyalite, sometimes stalactitic. Occasionally almost pulverulent.

Fracture imperfectly conchoidal and shining to earthy. **Very brittle.** $H = 3$. $G = 1.85-1.89$. Luster vitreous to subresinous, bright and waxy internally. Color pale sky-blue, sometimes greenish to deep green, brown, yellow or colorless. Streak uncolored. Translucent. Isotropic. $n = 1.47-1.49$.

Comp. — Hydrous aluminum silicate, $Al_2SiO_5 \cdot nH_2O$.

Inclusions are often present. The coloring matter of the blue variety is due to traces of chromium, and sometimes iron; white to green allophane and chromium must also be not uncommon. The green variety is colored by manganese and the yellowish and brown by iron. A highly ferruginous variety has been called *ferro-allophane*.

Pyr., etc. Yields much water in the closed tube. It B effervesces but is infusible. Gives a blue color on ignition with cobalt salt. In Gelsatin with hydrochloric acid.

Obs. — The phase is regarded as a result of the decomposition of some aluminous silicate (chert, etc.) and it often results in rusting fissures or scales in ore veins, especially those of copper or iron, often with limonite, at which it occurs. First described from Grafton, which of Sheffield. The group is variable. At Friesland near Bonn, Germany, is quite allophanic. In Arizona at the Tucson mine it is blue. From near Wickenburg, Arizona. In the Colorado River it is a Pennsylvanian at the Friesenfeld mine near a large Co. near at Cornwall, Lebanon Co.

Names such as *allophane*, and *epheron*, to appear, in allusion to its change of appearance under the microscope.

It occurs as a variety of a mixture of allophane and wavelite from Santa Rosa de Verber, state of Mexico, and in Arizona.

Mineral. $Al_2SiO_5 \cdot nH_2O$. In imperfect prisms. Stalactitic, massive. $H = 3$. $G = 1.85-1.89$. Color pale blue to brown. Infusible. From Grafton, Thurgau.

Schreibersite. $Al_2SiO_5 \cdot nH_2O$. Perhaps a native. Resembles allophane somewhat in its appearance. $H = 3-5$. $G = 1.45-2.06$. Color pale green or yellowish. Isotropic. $n = 1.58$. From Montserrat mountain near Frederick, Maryland. In Texas, Dyer, Austin, at the Falls of Little River, on the head Mt. Cherokee Co., Arizona.

The following are clay-like minerals or mineral substances. *Sinopite, smectite, colloidite*.

HYDROUS IRON SILICATES**CHLOROPAL.** Nontoxic.

Compact massive, with an opal-like appearance earthy.

$H = 2.5-4.5$. $G = 1.727-1.870$, earthy varieties, the second a conchoidal specimen 2.145, color pale greenish yellow and pistachio-green. Opaque to subtranslucent. Fragile. Fracture conchoidal and internally to earthy. Adheres freely to the tongue. Optical characters vary. Biaxial, \pm (also reported as $+$). Indices 1.46-1.65.

Var. — Chloropal has the above-mentioned characters, as I was named from the mineral occurring at Lohrstadt, Hesse, in Germany, and in California.

A beautiful pale green yellowish green and greenish with an opal-like feel, flattened and grows in pyrites under the same and is polished by friction. From Lohrstadt, Hesse. Perhaps it is also in Germany, extremely soft, like new cream soap, with a slightly resinous luster, not adhering to the tongue. From Wickenburg and near Zircow, a variety of greenish greenish green color, whence the name, as I found at Meissenberg in the Hiesengeorge, Thuringia, in thin fibrous masses, or as delicate laminae.

Comp. — A hydrated silicate of ferric iron, perhaps with the general formula $H_2FeSi_2O_7$, analogous to known and it is therefore frequently in-

cluded as a member of the Kaolin Group. Aluminia is present in some varieties.

The content of water is variable, depending upon atmospheric conditions. When heated the mineral loses water, and the color changes from green to brown or black, even when heated in a glass tube. The color change is reversible, and the mineral regains its original color when exposed to air. It is produced in the decomposition of aluminous silicates, and is found in the high temperature zone of the Earth's crust.

Pyx etc. Information concerning the mineral.

Obs. It is a colorless to light green mineral, often above chlorite in the ground at Pikes Peak, Colorado. It is also found in the ground at Pikes Peak, Colorado. It is also found in the ground at Pikes Peak, Colorado.

Herbertite. A mineral of the orthorhombic system. It is found in the ground at Pikes Peak, Colorado.

Mineralogy. Zirconium. It is a colorless to light green mineral, often above chlorite in the ground at Pikes Peak, Colorado.

Color. It is a colorless to light green mineral, often above chlorite in the ground at Pikes Peak, Colorado.

Mineralogy. A mineral of the orthorhombic system. It is found in the ground at Pikes Peak, Colorado.

Herbertite. A mineral of the orthorhombic system. It is found in the ground at Pikes Peak, Colorado. It is also found in the ground at Pikes Peak, Colorado. It is also found in the ground at Pikes Peak, Colorado.

Canbyite. A mineral of the orthorhombic system. It is found in the ground at Pikes Peak, Colorado. It is also found in the ground at Pikes Peak, Colorado. It is also found in the ground at Pikes Peak, Colorado.

HYDROUS MANGANESE SILICATES

Bementite. $H_2Mn_2Si_2O_7 \cdot 4H_2O$. Orthorhombic. It is found in the ground at Pikes Peak, Colorado. It is also found in the ground at Pikes Peak, Colorado. It is also found in the ground at Pikes Peak, Colorado.

Ectopite. $Mn_2Si_2O_7 \cdot 4H_2O$. Monoclinic. It is found in the ground at Pikes Peak, Colorado. It is also found in the ground at Pikes Peak, Colorado. It is also found in the ground at Pikes Peak, Colorado.

Crystallography. It is a colorless to light green mineral, often above chlorite in the ground at Pikes Peak, Colorado.

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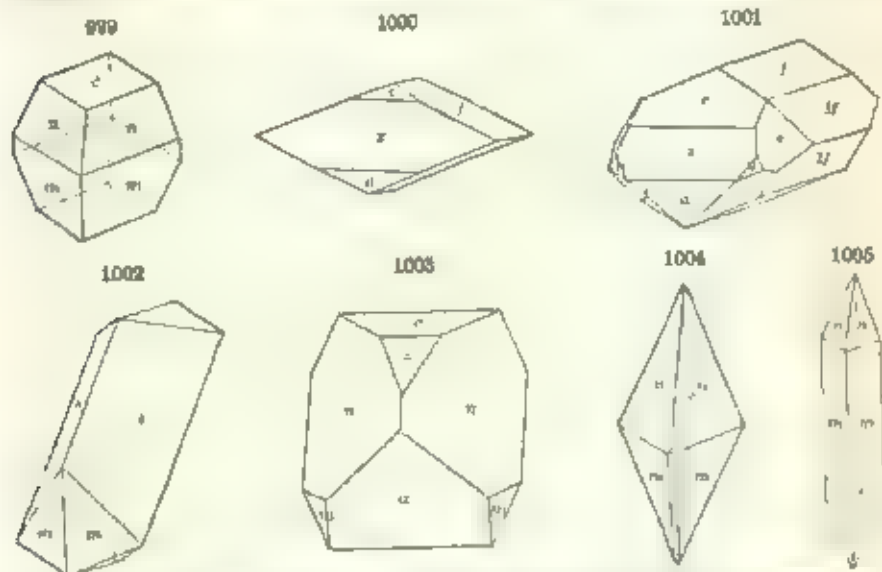
Crystallography. It is a colorless to light green mineral, often above chlorite in the ground at Pikes Peak, Colorado.

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Crystallography. It is a colorless to light green mineral, often above chlorite in the ground at Pikes Peak, Colorado.

Twins: tw pl $a(100)$ rather common both contact-twins and cruciform penetration-twins. Crystals very varied in habit, often wedge-shaped and flattened $a(100)$, also prismatic. Sometimes massive, compact, rarely lamellar.



X-ray study shows a unit cell agreeing in all dimensions with the crystal constants given above and which contains four molecules. The SiO_4 groups present are independent of each other. The Ti atoms are in the center of an octahedral group of six O atoms and the Ca atoms lie between seven O atoms.

Cleavage $m(110)$ rather distinct, $a(100)$, $l(112)$ imperfect, in greenovite, $a(111)$ easy, $l(111)$ less so. Parting after easy $m(221)$ due to twinning lamellae. $H = 5-5.5$. $G = 3.4-3.56$. Luster adamantine to resinous. Color brown, gray, yellow, green, rose-red and black. Streak white, slightly reddish in greenovite. Transparent to opaque.

Pleochroism in general rather feeble but distinct in deep-colored kinds. Z , red with tinge of yellow; Y , yellow, often greenish. X nearly colorless. Optically $+$. Ax pl $a(010)$; Z nearly \perp to $Z \wedge c$ axis $= +51^\circ$. Dispersion $\rho > \gamma$ very large, and hence the peculiarity of the axial interference-figure in white light. Axial angles variable but usually small. $\alpha = 1.900$. $\beta = 1.907$. $\gamma = 2.034$.

Variety: Ordinary α Titanite brown to black (the original being thus colored, also opaque or subtransparent). β Aphane, comes from outer, younger, of the rocks, as yellow-greenish etc. γ also often transparent, the original was yellow. δ greenish apple-green. Aphane. Sometimes α or β on a greenish band. Lath-like α brown, opaque or subtransparent, of the form in Fig. 900.

Titanite is a white, mostly granular silicate product of igneous and metamorphic action in certain crystalline rocks. It is also abundant and occurs in a few, also in greenish, etc. γ also often transparent, the original was yellow. δ greenish apple-green. Aphane. Sometimes α or β on a greenish band. Lath-like α brown, opaque or subtransparent, of the form in Fig. 900.

Mineralization: Greenovite, red or rose-colored, owing to the presence of a little manganese. In the Marcell. Piedmont. Italy, greenovite is a variety of titanite.

Composition: Titanite or greenovite. Lath-like granular, atacamite, etc. α or β . Red. α or β or γ or δ contains about 12 per cent. γ , δ or ϵ . Found near Arundel in Aust.

bate with a titanate RNb_2O_7 , $R = Ti, Th$, etc. Fluorine is also present. The formula suggested by X-ray study is $Nb_2O_7(R_2O)_2(Nb_2O_7)(F)_2$.

Obs. Found in nephelite-syenite at Frestokkåsen and Lørvik, Norway, on the island Læsø, opposite Skagen, and in syenite porphyry at the Långsund, Sweden, near Mårsk in the Hårfors Mountains. Also in syenite at Långsund, Sweden, and in syenite porphyry at Långsund, Sweden. A variety of, elsewhere from near Wisconsin, Marquette Co., Wisconsin, has been described.

Koppite Nb_2O_7 is a pyrometate of cerium, calcium, iron, etc. near pyrochlore. The formula is $Nb_2O_7(CeO)_2(CaO)_2(FeO)_2$. It is a black mineral. $H = 5.5$, $G = 5.4$. Found in syenite at Långsund, Sweden, and in syenite porphyry at Långsund, Sweden.

Batchettite Nb_2O_7 is a pyrometate of cerium, calcium, iron, etc. near pyrochlore. The formula is $Nb_2O_7(CeO)_2(CaO)_2(FeO)_2$. It is a black mineral. $H = 5.5$, $G = 5.4$. Found in syenite at Långsund, Sweden, and in syenite porphyry at Långsund, Sweden.

Black niobate A niobate and titanate of cerium, calcium, iron, etc. near pyrochlore. The formula is $Nb_2O_7(CeO)_2(CaO)_2(FeO)_2$. It is a black mineral. $H = 5.5$, $G = 5.4$. Found in syenite at Långsund, Sweden, and in syenite porphyry at Långsund, Sweden.

Elbowwhite Approximately $CaO(Nb_2O_7)2H_2O$. Contains also uranium, cerium, etc. Isometric. In small octahedra or cubes. $H = 4$, $G = 3.4$. Found in syenite at Långsund, Sweden, and in syenite porphyry at Långsund, Sweden. Also in syenite at Långsund, Sweden, and in syenite porphyry at Långsund, Sweden.

Neotantalite A niobate and tantalate of iron, manganese, etc. Isometric in octahedra. $H = 5.5$, $G = 5.2$. Color clear yellow. $n = 1.96$. Found with kashin in the Långsund, Sweden.

Chalcophyllite $Nb_2O_7(Sb_2O_3)_2$. Isometric. In small octahedra. $H = 5.5$, $G = 5.4$. Color dark green. Crystals show a characteristic metallic luster. Isometric. $n = 1.92$. Found in syenite at Långsund, Sweden, and in syenite porphyry at Långsund, Sweden. Also in syenite at Långsund, Sweden, and in syenite porphyry at Långsund, Sweden.

Samburite A niobate of cerium, calcium, iron, etc. Isometric. In octahedra. $H = 5.5$, $G = 5.4$. Found in syenite at Långsund, Sweden, and in syenite porphyry at Långsund, Sweden.

Microite Nb_2O_7 is a pyrometate of cerium, calcium, iron, etc. near pyrochlore. The formula is $Nb_2O_7(CeO)_2(CaO)_2(FeO)_2$. It is a black mineral. $H = 5.5$, $G = 5.4$. Found in syenite at Långsund, Sweden, and in syenite porphyry at Långsund, Sweden. Also in syenite at Långsund, Sweden, and in syenite porphyry at Långsund, Sweden.

Fergusonite Essentially a metaniobate (and tantalate) of yttrium with cerium, cerium, cerium, etc., in varying amounts, also iron, calcium, etc. General formula $R_2(Nb,Ta)_2O_7$ with $R = Y, Er, Ce$.

FERGUSONITE. Yttria. Bright.

Tetragonal-pyramidal. Axis $c = 1.4647$. Crystals pyramidal or prismatic in habit. X-ray study shows that fergusonite normally has a tetragonal atomic structure but on heating to $400^\circ C$ it becomes crystalline, tetragonal.

Cleavage $\{111\}$ in traces. Fracture subconchoidal. Brittle. $H = 5.5-6$, $G = 5.8$ diminishing to 4.3 when highly hydrated. Luster externally dull, on the fracture brilliantly vitreous and lustrous. Color brownish black, in thin sections pale liver-brown. Striae pale brown. Subtranslucent to opaque. Index, 2.19.

Comp. Essentially a metaniobate (and tantalate) of yttrium with cerium, cerium, cerium, etc., in varying amounts, also iron, calcium, etc.

General formula $R_2(Nb,Ta)_2O_7$ with $R = Y, Er, Ce$.

Water is usually present and sometimes in considerable amount, but probably not an original constituent; the specific gravity falls as the amount increases.

Obs. Ferganite was first discovered from the J. J. Smith district in Greenland. Also found in Sweden at Västana, northeast of Åre. In Norway, it occurs in Aust-Agder at Høne near Arendal, and at Harnesmyr on the island of Tromsøfjorden, at Ege on the coast south of Tromsø, and at Måse in the Rukwina district in Ceylon. In Madagascar from near Antananarivo, west of Mandrivo and to the southwest of Taranant. It is found in Japan at Takayama, Mio.

In the United States ferganite is found at Wakeport near Worcester, Massachusetts, in the Brimleyville gold district, Burke Co., North Carolina, also from near Spruce Pine, Mitchell Co., North Carolina. At the gadolinite workings in Lead Co., Texas, there is a considerable quantity of ferganite, sometimes weighing over a pound; some large rough crystals. It is from Amherst Co., Virginia, erroneously thought to contain cerium, has been shown to be identical with ferganite.

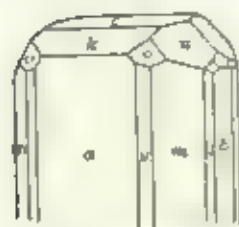
RIEDELITE. A niobate of the titanite family; very similar to ferganite but with a higher content of titanate, and probably to be classed as a variety of that mineral. X-ray study shows a tetragonal structure. $H = 5.5$, $G = 4.1$. Color yellow brown. Isotropic, $n = 2.0$. In pegmatite at Røss, Aust-Agder, Norway.

COLUMBITE-TANTALITE

Orthorhombic. Axes $a : b : c = 0.8285 : 1 : 0.8898$

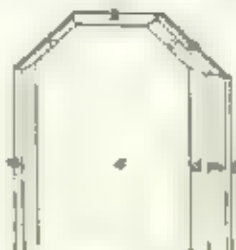
| | | | |
|------|----------------------------|------|----------------------------|
| W | 210 \wedge 210 = 45° 0' | W | 101 \wedge 021 = 60° 40' |
| SW | 110 \wedge 110 = 79° 17' | SW | 00 \wedge 11 = 5° 16' |
| W | 130 \wedge 130 = 43° 50' | SW | 001 \wedge 13 = 43° 48' |
| SW | 001 \wedge 103 = 19° 42' | SW | 130 \wedge 13 = 9° 17' |
| SW | 001 \wedge 023 = 30° 41' | SW | 133 \wedge 133 = 79° 54' |

1006



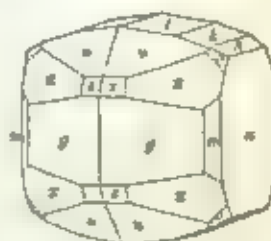
Middletown

1007



Black Hills

1008



Greenland

Twins tw pl $\{021\}$ common, usually contact-twins, heart-shaped (Fig 407, p. 180); also penetration-twins, further tw pl $\{012\}$ rare (Fig 460, p. 191). Crystals short prismatic, often rectangular prisms with the three pinacoids prominent, also thin tabular $\{100\}$, the pyramids often but slightly developed, sometimes, however, acutely terminated by $\{113\}$ alone. Also in large groups of parallel crystals, and massive.

X-ray study of the structure shows that the O atoms are arranged about the Nb and the Fe atoms at the points of octahedra. The Nb-O groups form a chain with opposite edges of the octahedra shared by the adjoining groups. The Fe-O groups have the same arrangement. These two different chains are connected by the sharing of octahedral corners with each other. The structure shows a close resemblance to that of brookite.

Cleavage: $a(100)$ rather distinct, $b(010)$ less so. Fracture subconchoidal to uneven. Brittle. $H = 6$, $G = 5.3-7.3$, varying with the composition (see below). Luster submetallic, often very brilliant, sub-resinous. Color iron-black, grayish and brownish black, opaque, rarely reddish brown and

Polycrase. A niobate and tantalate of vitreous, earthy, ceramic, granular, like massive crystals, thin prisms or octahedra. Fracture conchoidal. $d = 2.4$, $G = 4.9$, $H = 5.0$. Under stress of compression, breaks in cleavage planes. Lustre glassy. $n = 1.70$. Found in Norway as crystals in granitic rocks and in small veins in granite on the island of Hestera, Vest-Agder, near Arendal, etc. From Sweden near Åmola in Jönköping, Sweden, in the Åmola stock, occurs a well-formed polymorphous mass in thin plates. In Hestera, Co. North Carolina, the crystals are up to 1 cm. in diameter and yellowish-brown, rather black. In Åmola, Sweden, in a mass of 4 cm. in diameter, the crystals are 1 cm. in diameter, thin plates, up to 1 cm. in diameter.

Blomstrandine Phosphate. Niobate and tantalate of vitreous, earthy, ceramic, granular, like massive crystals, thin prisms or octahedra. Fracture conchoidal. $d = 2.4$, $G = 4.9$, $H = 5.0$. Under stress of compression, breaks in cleavage planes. Lustre glassy. $n = 1.70$. Found in Norway as crystals in granitic rocks and in small veins in granite on the island of Hestera, Vest-Agder, near Arendal, etc. From Sweden near Åmola in Jönköping, Sweden, in the Åmola stock, occurs a well-formed polymorphous mass in thin plates. In Hestera, Co. North Carolina, the crystals are up to 1 cm. in diameter and yellowish-brown, rather black. In Åmola, Sweden, in a mass of 4 cm. in diameter, the crystals are 1 cm. in diameter, thin plates, up to 1 cm. in diameter.



Polycrase

Blomstrandine Phosphate. Niobate and tantalate of vitreous, earthy, ceramic, granular, like massive crystals, thin prisms or octahedra. Fracture conchoidal. $d = 2.4$, $G = 4.9$, $H = 5.0$. Under stress of compression, breaks in cleavage planes. Lustre glassy. $n = 1.70$. Found in Norway as crystals in granitic rocks and in small veins in granite on the island of Hestera, Vest-Agder, near Arendal, etc. From Sweden near Åmola in Jönköping, Sweden, in the Åmola stock, occurs a well-formed polymorphous mass in thin plates. In Hestera, Co. North Carolina, the crystals are up to 1 cm. in diameter and yellowish-brown, rather black. In Åmola, Sweden, in a mass of 4 cm. in diameter, the crystals are 1 cm. in diameter, thin plates, up to 1 cm. in diameter.

Betafite. A niobate and tantalate of vitreous, earthy, ceramic, granular, like massive crystals, thin prisms or octahedra. Fracture conchoidal. $d = 2.4$, $G = 4.9$, $H = 5.0$. Under stress of compression, breaks in cleavage planes. Lustre glassy. $n = 1.70$. Found in Norway as crystals in granitic rocks and in small veins in granite on the island of Hestera, Vest-Agder, near Arendal, etc. From Sweden near Åmola in Jönköping, Sweden, in the Åmola stock, occurs a well-formed polymorphous mass in thin plates. In Hestera, Co. North Carolina, the crystals are up to 1 cm. in diameter and yellowish-brown, rather black. In Åmola, Sweden, in a mass of 4 cm. in diameter, the crystals are 1 cm. in diameter, thin plates, up to 1 cm. in diameter.

Blomstrandine Phosphate. Niobate and tantalate of vitreous, earthy, ceramic, granular, like massive crystals, thin prisms or octahedra. Fracture conchoidal. $d = 2.4$, $G = 4.9$, $H = 5.0$. Under stress of compression, breaks in cleavage planes. Lustre glassy. $n = 1.70$. Found in Norway as crystals in granitic rocks and in small veins in granite on the island of Hestera, Vest-Agder, near Arendal, etc. From Sweden near Åmola in Jönköping, Sweden, in the Åmola stock, occurs a well-formed polymorphous mass in thin plates. In Hestera, Co. North Carolina, the crystals are up to 1 cm. in diameter and yellowish-brown, rather black. In Åmola, Sweden, in a mass of 4 cm. in diameter, the crystals are 1 cm. in diameter, thin plates, up to 1 cm. in diameter.

Blomstrandine Phosphate. Niobate and tantalate of vitreous, earthy, ceramic, granular, like massive crystals, thin prisms or octahedra. Fracture conchoidal. $d = 2.4$, $G = 4.9$, $H = 5.0$. Under stress of compression, breaks in cleavage planes. Lustre glassy. $n = 1.70$. Found in Norway as crystals in granitic rocks and in small veins in granite on the island of Hestera, Vest-Agder, near Arendal, etc. From Sweden near Åmola in Jönköping, Sweden, in the Åmola stock, occurs a well-formed polymorphous mass in thin plates. In Hestera, Co. North Carolina, the crystals are up to 1 cm. in diameter and yellowish-brown, rather black. In Åmola, Sweden, in a mass of 4 cm. in diameter, the crystals are 1 cm. in diameter, thin plates, up to 1 cm. in diameter.

Epistilite. A niobate of ammonium, cerium, and iron. Shows a glassy, earthy, ceramic, granular, like massive crystals, thin prisms or octahedra. Fracture conchoidal. $d = 2.4$, $G = 4.9$, $H = 5.0$. Under stress of compression, breaks in cleavage planes. Lustre glassy. $n = 1.70$. Found in Norway as crystals in granitic rocks and in small veins in granite on the island of Hestera, Vest-Agder, near Arendal, etc. From Sweden near Åmola in Jönköping, Sweden, in the Åmola stock, occurs a well-formed polymorphous mass in thin plates. In Hestera, Co. North Carolina, the crystals are up to 1 cm. in diameter and yellowish-brown, rather black. In Åmola, Sweden, in a mass of 4 cm. in diameter, the crystals are 1 cm. in diameter, thin plates, up to 1 cm. in diameter.

Oxygen Salts

4. PHOSPHATES, ARSENATES, VANADATES, ANTIMONATES

A. Anhydrous Phosphates, Arsenates, Vanadates, Antimonates

Normal phosphoric acid is H_3PO_4 , and consequently normal phosphates have the formulas R_3PO_4 , $R_2(PO_4)_2$, and $R(PO_4)_3$, and similarly for the arsenates, etc. Only a comparatively small number of species conform to this simple formula. Most species contain more than one metal element, and in the prominent Apatite group the radical, $(CaF)_2$, $(CaCl)_2$, or $(PbCl)_2$ enters, in the Wagerite Group we have similarly $(RF)_2$ or $(ROH)_2$.

Triphosphite occurs at Branchville, Fairfield Co., Connecticut. Also in Maine from Norway, and at 6 and 6 miles in the region of also from Pasa, San Diego Co., California. Name from trisphosphite and phosphite.

Metriphosphate — Na_2MgPO_4 . Near triphosphite in form, cleavage massive cleavable. $\text{H} = 4 \times 5$, $\text{G} = 3.41$, easily soluble in water; white-yellow, opaque + As in 1000. $\text{Z} = 1.520$, $\text{a} = 0.71$, $\text{b} = 0.74$, $\text{c} = 1.00$, $2\text{V} = 90^\circ$ strong dispersion, $\text{a} < \text{v}$. Occurs sparingly at Branchville, Fairfield Co., Connecticut.

Graftonite — $\text{Fe}_2\text{MgCa}_2\text{P}_2\text{O}_7$. Monoclinic. Lamellar. Basal cleavage. $\text{H} = 5$, $\text{G} = 3.7$, fusible. Crystals from water, dark green, dark red, abundant in crystalline + As in 1000. $\text{Z} = 1.520$, $\text{a} = 0.71$, $\text{b} = 0.74$, $\text{c} = 1.00$, $2\text{V} = 90^\circ$, $\text{a} < \text{v}$. 1724. 25. much in the form of a small, rounded, single crystal with a small in a prismatic form. Found at Grafton, New Hampshire.

Merrillite — $\text{Ca}_2\text{Mg}_2\text{P}_2\text{O}_7$. Monoclinic. $\text{H} = 5$, $\text{G} = 3.41$, $\text{Z} = 1.520$, $\text{a} = 0.71$, $\text{b} = 0.74$, $\text{c} = 1.00$, $2\text{V} = 90^\circ$, $\text{a} < \text{v}$. Found in a small, rounded, single crystal with a small in a prismatic form.

Behrmite — $\text{Al}_2\text{Si}_2\text{P}_2\text{O}_7$. Hexagonal. Perfect basal cleavage. 1. grayish to greenish white crystals, abundant in the form of small, rounded, single crystals. $\text{H} = 5$, $\text{G} = 1.50$, $\text{Z} = 1.520$, $\text{a} = 0.71$, $\text{b} = 0.74$, $\text{c} = 1.00$, $2\text{V} = 90^\circ$, $\text{a} < \text{v}$. Crystals from water, dark green, dark red, abundant in the form of small, rounded, single crystals. Found at Behr, New Hampshire.

Beryllonite — $\text{Al}_2\text{Si}_2\text{P}_2\text{O}_7$. Hexagonal. Perfect basal cleavage. 1. grayish to greenish white crystals, abundant in the form of small, rounded, single crystals. $\text{H} = 5$, $\text{G} = 1.50$, $\text{Z} = 1.520$, $\text{a} = 0.71$, $\text{b} = 0.74$, $\text{c} = 1.00$, $2\text{V} = 90^\circ$, $\text{a} < \text{v}$. Crystals from water, dark green, dark red, abundant in the form of small, rounded, single crystals. Found at Beryllon, New Hampshire.

Kollinonite — $\text{Al}_2\text{Si}_2\text{P}_2\text{O}_7$. Hexagonal. Perfect basal cleavage. 1. grayish to greenish white crystals, abundant in the form of small, rounded, single crystals. $\text{H} = 5$, $\text{G} = 1.50$, $\text{Z} = 1.520$, $\text{a} = 0.71$, $\text{b} = 0.74$, $\text{c} = 1.00$, $2\text{V} = 90^\circ$, $\text{a} < \text{v}$. Crystals from water, dark green, dark red, abundant in the form of small, rounded, single crystals. Found at Kollinon, New Hampshire.

Trimerite — $\text{Al}_2\text{Si}_2\text{P}_2\text{O}_7$. Hexagonal. Perfect basal cleavage. 1. grayish to greenish white crystals, abundant in the form of small, rounded, single crystals. $\text{H} = 5$, $\text{G} = 1.50$, $\text{Z} = 1.520$, $\text{a} = 0.71$, $\text{b} = 0.74$, $\text{c} = 1.00$, $2\text{V} = 90^\circ$, $\text{a} < \text{v}$. Crystals from water, dark green, dark red, abundant in the form of small, rounded, single crystals. Found at Trimerite, New Hampshire.

Saxony — $\text{Al}_2\text{Si}_2\text{P}_2\text{O}_7$. Hexagonal. Perfect basal cleavage. 1. grayish to greenish white crystals, abundant in the form of small, rounded, single crystals. $\text{H} = 5$, $\text{G} = 1.50$, $\text{Z} = 1.520$, $\text{a} = 0.71$, $\text{b} = 0.74$, $\text{c} = 1.00$, $2\text{V} = 90^\circ$, $\text{a} < \text{v}$. Crystals from water, dark green, dark red, abundant in the form of small, rounded, single crystals. Found at Saxony, New Hampshire.

Apatite Group

| General formula | $\text{R}_2(\text{F}, \text{Cl}) (\text{P}, \text{As}, \text{V})_2\text{O}_7 = (\text{R}_2(\text{F}, \text{Cl}) (\text{P}, \text{As}, \text{V})_2\text{O}_7)_n$ | |
|---------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------|
| Apatite | $\text{Ca}_5(\text{F}, \text{Cl}, \text{PO}_4)_3$ | Fluor-apatite $\epsilon = 0.7340$ |
| | or $\text{Ca}_5(\text{F}, \text{Cl}, \text{PO}_4)_3$ | Chlor-apatite |
| Pyromorphite | $\text{Pb}_5(\text{F}, \text{Cl}, \text{PO}_4)_3$ | 0.7362 |
| Mimetite | $\text{Pb}_5(\text{F}, \text{Cl}, \text{AsO}_4)_3$ | 0.7224 |
| Vanadinite | $\text{Pb}_5(\text{F}, \text{Cl}, \text{VO}_4)_3$ | 0.7122 |

In addition to the above species there are also certain intermediate compounds containing lead and calcium, others with strontium and barium, or arsenic or antimony, as noted by and. Further the more common species are also noted by being a thus for. The radicals CaO , Al_2O_3 , FeO , MgO , ZnO , CuO , NiO , CoO , MnO , BaO , SrO , PbO , As_2O_5 , V_2O_5 , F_2 , Cl_2 , H_2O , and SO_4 in addition to usual radicals. *Ferromerite* contains strontium.

The species of the **APATITE GROUP** crystallize in the hexagonal system, but as shown, either by the tabular figures, or by stereographic figures, that they belong to the triprismatic class p. 116. They are chemically phosphates, arsenates, vanadates of calcium or lead, also manganese with fluorine or fluorine. The latter element is probably present as a univalent radical Ca^+ (or CaCl), etc., in general $\text{R}_2(\text{F}, \text{Cl})$, replacing one hydrogen atom in the acid $\text{H}_2(\text{PO}_4)_2$, so that the general formula is $\text{R}_2(\text{R}_1, \text{PO}_4)_3$, and similarly for the arsenates. This is a more correct way of viewing the composition than the other method sometimes adopted, viz., $3\text{R}_1\text{PO}_4 \cdot \text{R}_2\text{F}_2$, etc.

Comp. $(\text{PbCl Pb}_2)(\text{VO}_4)_2$, also written $3\text{Pb}_2\text{V}_2\text{O}_7 \cdot \text{PbCl}_2$ = Vanadium pentoxide 19.4, lead protoxide 78.7, chlorine 2.5 = 100.0, or Lead vanadate 90.2, lead chloride 9.8 = 100.

Phosphorus is sparingly present, also sometimes arsenic, both replacing vanadium. In *endliche* the ratio of V : As = 1 : 1 nearly.

Pyr., etc. - In the closed tube decomposes and yields a faint white sublimate. In fusion dissolves in carbonic acid, and later a mass, which on cooling yields a white lead and a coating of lead carbonate, after completely dissolving to leave a thick black resin, which gives with sol. of phosphoric acid an emerald-green bead in H.F., which becomes light yellow to colorless on passing by hydrosulphuric acid.

Obs. Vanadate is an uncommon mineral usually found in altered lead deposits. One instance is recorded at Beres in near Ekaterinburg in the Ural Mts. near Pionersk, in the district of Apatin, near the Sierra Nevada, Ariz. Another is at the top of the Soledad at W. Nevada. It is found in the form of small black, lustrous, large or small crystals at Lijón, Mérida, Michoacán, near San Juan, Mexico. From Chocoma, in the Maricao mts., Pinar del Rio, near the Sierra de Guadalupe, Argentina. Vanadate was also found from Zapopan, Hidalgo, Mexico.

In the United States frequently found in the mining regions of Arizona and New Mexico, often associated with wolfram and cerussite. In Arizona the chief localities were at the Red Mountain, etc., and at the top of the highest deep red craters, from the Marathon gold mine at Soledad near Tucson to the Catalina Mts. Plaster Co., from the old Yaquina gold mine, Plaster Co., from Yavapai Co. in ore on barren shaped craters in the Gila district, Graham Co. In New Mexico, Sierra Co., in Lake Valley, with Aztec and Plaster, near Georgetown, Grant Co., and in heavy near Magdalena, Socorro Co. From the Black Hills, South Dakota.

Use. A source of vanadium and a variety of lead.

REYNOLDSITE. Also recorded from the same variety of minerals. Massive, greenish, color yellow with white streak, $d = 1.948$, $r = 1.958$ (parallel to b). From Vermont. Occurs at Langbanahyttan and Fajberg near Farnberg. Also from Franklin, Sussex Co., New Jersey.

Wagnerite Group. Monoclinic

| | | a | b | c | β |
|--------------|------------------------------------------------|--------|-----|--------|---------|
| Wagnerite | $(\text{MgF MgP})_2$ | 1.9145 | 1 | 1.5059 | 71° 53' |
| Triphite | $(\text{RfRfP})_2$, R = Fe, Mn = 2, 1, 1 etc. | 1.8572 | 1 | 1.4925 | 71° 48' |
| Triphloisite | $(\text{RfOH RfP})_2$, R = Mn, Fe = 3 | 1.8572 | 1 | 1.4925 | 71° 48' |
| Adelite | $(\text{MgOH CaAsO}_4)_2$ | 2.1978 | 1 | 1.5612 | 73° 15' |
| Tilasite | $(\text{MgAsAsO}_4)_2$ | | | | |
| Sarkinite | $(\text{MnOH})_2\text{AlnAsO}_4$ | 2.0017 | 1 | 1.5154 | 82° 13' |

Phosphates (and arsenates) of magnesium (carbonate), iron and manganese containing fluorine (also hydroxyl). Formula R_2FPO_4 or $(\text{RfRf})\text{RPO}_4$, etc.

WAGNERITE

Monoclinic. Axes, see above. Crystals sometimes large and coarse. Also massive.

Cleavage $a(100)$, $m(110)$ imperfect, $c(001)$ in traces. Fracture uneven and splintery. Brittle. $H = 5-5.5$. $G = 3.07-3.14$. Luster vitreous. Streak white. Color yellow, of different shades; often grayish, also flesh-red, greenish. Translucent. Optically +. Ax. pl. (010). $Z \wedge c$ axis = 21°. $2\psi = 26^\circ$ (approx.) $\alpha = 1.569$, $\beta = 1.570$, $\gamma = 1.582$.

Comp. A fluor-phosphate of magnesium, $(\text{MgF MgP})_2$, or $\text{Mg}_2\text{P}_2\text{O}_7 \cdot \text{MgF}_2$ = Phosphorus pentoxide 43.8, magnesia 49.3, fluorine 11.8 = 104.9, deduct O = 2F, 4.9 = 100. A little calcium replaces part of the magnesium.

Vernand, Sweden, also at Långbanhyttan. Polysynthetic and Xanthoprase from the 935 mine, Örebro, Sweden, and Xanthoprase from Fälsberg, Sweden, are also all the same.

Arsenomite. $2Mn(OH) \cdot Mn_2As_2O_7$. Orthorhombic. Cleavage {01} (oblique). Optical: $n_x = 1.60$, $n_y = 1.60$, $n_z = 1.60$. $\alpha = 1.88$, $\beta = 1.810$, $\gamma = 1.816$. From Långbanhyttan, Vermland, Sweden.

Artopside. A phosphate of iron, manganese, etc. $4R_2PO_4 \cdot 9R_2P_2O_7$. Monoclinic. Perfect cleavage $\{110\}$. Optical: $n_x = 1.71$, $n_y = 1.70$, $n_z = 1.70$. Color dark green. Pleochroic: $X = Y =$ colorless, $Z =$ pale green. Found massive at Serro Branco, Paraíba, Brazil.

Sarcopside. Perhaps $2R_2P_2O_7 \cdot RE_2P_2O_7$; $R = Fe, Mn, Ca$. Monoclinic? In irregular shape, is a distorted mica-like plate, it (from Deerling with fibers of apatite) is very age, a brownish green, or greenish-lavender to fibers. $H = 4$, $G = 3.64$, $\alpha = 1.67$. Luster silky. Color fresh red-lavender, after weathering or exposure to the air, it becomes brown. Optical: $n_x = 1.725$, $n_y = 1.725$, $n_z = 1.725$. Found in a pegmatite vein near Metchuon, Soudan. Also found in a small pegmatite vein in Deerling, New Hampshire.

Trigonalite. $2H_2Al_2Si_2O_7 \cdot 2H_2O$. Monoclinic-clinochordal. In small wedge-shaped crystals. Perfect cleavage $\{110\}$. Optical: $n_x = 1.60$, $n_y = 1.60$, $n_z = 1.60$. $\alpha = 1.60$, $\beta = 1.60$, $\gamma = 1.60$. From LA ghanahyttan, Vermland, Sweden.

Schützite. $2H_2Al_2Si_2O_7 \cdot 2H_2O$. Monoclinic. In small crystals. Cleavage, good $\{110\}$. Transparent, colorless. Strains of crystals to exhibit a lamellar structure. Optical: $n_x = 1.60$, $n_y = 1.60$, $n_z = 1.60$. $\alpha = 1.60$, $\beta = 1.60$, $\gamma = 1.60$. Occurs on argillite and is a relic from the last stage of the South West Africa.

Herderite. A phosphate of barium and cerium. $CaBa_2(PO_4)_2$. In trimorphic crystals, colorless, or brownish-yellow. $H = 5$, $G = 3.6$. Luster vitreous. Color brownish and greenish white. Optical: $n_x = 1.60$, $n_y = 1.60$, $n_z = 1.60$. $\alpha = 1.60$, $\beta = 1.60$, $\gamma = 1.60$. From the mine of Herder, near the Pyrenees, Spain. Also found in the mine of Herder, near the Pyrenees, Spain. Also found in the mine of Herder, near the Pyrenees, Spain. Also found in the mine of Herder, near the Pyrenees, Spain.

The following minerals are similar and are commonly placed together in the Hamphite group. They are all members of the Hamphite group.

Goraisite. A basic phosphate of aluminum and strontium. $2Al_2(OH) \cdot P_2O_7$. In small crystals, colorless, or brownish-yellow. Luster vitreous. $H = 4.5$, $G = 3.6$. Luster vitreous. Color brownish and greenish white. Optical: $n_x = 1.60$, $n_y = 1.60$, $n_z = 1.60$. $\alpha = 1.60$, $\beta = 1.60$, $\gamma = 1.60$. Found in the mine of Gorais, near the Pyrenees, Spain. Also found in the mine of Gorais, near the Pyrenees, Spain. Also found in the mine of Gorais, near the Pyrenees, Spain.

Plumbogummite. A basic phosphate of lead and strontium. $2Pb(OH) \cdot P_2O_7$. In small crystals, colorless, or brownish-yellow. Luster vitreous. $H = 4.5$, $G = 3.6$. Luster vitreous. Color brownish and greenish white. Optical: $n_x = 1.60$, $n_y = 1.60$, $n_z = 1.60$. $\alpha = 1.60$, $\beta = 1.60$, $\gamma = 1.60$. Found in the mine of Plumbogummite, near the Pyrenees, Spain. Also found in the mine of Plumbogummite, near the Pyrenees, Spain. Also found in the mine of Plumbogummite, near the Pyrenees, Spain.

Hutchinsonite. A basic phosphate of lead and strontium. $2Pb(OH) \cdot P_2O_7$. In small crystals, colorless, or brownish-yellow. Luster vitreous. $H = 4.5$, $G = 3.6$. Luster vitreous. Color brownish and greenish white. Optical: $n_x = 1.60$, $n_y = 1.60$, $n_z = 1.60$. $\alpha = 1.60$, $\beta = 1.60$, $\gamma = 1.60$. Found in the mine of Hutchinsonite, near the Pyrenees, Spain. Also found in the mine of Hutchinsonite, near the Pyrenees, Spain. Also found in the mine of Hutchinsonite, near the Pyrenees, Spain.

Herzenbergite. A basic phosphate of lead and strontium. $2Pb(OH) \cdot P_2O_7$. In small crystals, colorless, or brownish-yellow. Luster vitreous. $H = 4.5$, $G = 3.6$. Luster vitreous. Color brownish and greenish white. Optical: $n_x = 1.60$, $n_y = 1.60$, $n_z = 1.60$. $\alpha = 1.60$, $\beta = 1.60$, $\gamma = 1.60$. Found in the mine of Herzenbergite, near the Pyrenees, Spain. Also found in the mine of Herzenbergite, near the Pyrenees, Spain. Also found in the mine of Herzenbergite, near the Pyrenees, Spain.

Crandallite. $Ca_2(Al_2Si_2O_7) \cdot P_2O_7 \cdot 2H_2O$. Probably orthorhombic. In small crystals, colorless, or brownish-yellow. Luster vitreous. $H = 4$, $G = 3.6$. Luster vitreous. Color brownish and greenish white. Optical: $n_x = 1.60$, $n_y = 1.60$, $n_z = 1.60$. $\alpha = 1.60$, $\beta = 1.60$, $\gamma = 1.60$. Found in the mine of Crandallite, near the Pyrenees, Spain. Also found in the mine of Crandallite, near the Pyrenees, Spain. Also found in the mine of Crandallite, near the Pyrenees, Spain.

parent to translucent. Optically - Ax pl 010. Z nearly \perp a axis.
 $\alpha = 1.73$, $\beta = 1.87$, $\gamma = 1.91$. 2V maximum. Strong dispersion $\rho < \gamma$.

Comp. $(\text{Cu}, \text{As})_{10-30} (\text{OH})_2$ or $60 (\text{OH})_2$. Arsenic pentoxide 30.3, cupric oxide 62.6, water 7.1 = 100.

Pyr., etc. Same as for olivine.

Obs. - Found in the region of Carwell at Gwersyll St. Day, Herts. etc. also in the district of the Great Ouse, Bedfordshire. It is also found in the district of the Great Ouse, Bedfordshire. It is also found in the district of the Great Ouse, Bedfordshire.

Named in allusion to the fact that it is oblique to the sides of the crystal. It is also found in the district of the Great Ouse, Bedfordshire. It is also found in the district of the Great Ouse, Bedfordshire.

Dihydrate $(\text{Cu}, \text{As})_{10-30} (\text{OH})_2$ or $60 (\text{OH})_2$. Arsenic pentoxide 30.3, cupric oxide 62.6, water 7.1 = 100. It is also found in the district of the Great Ouse, Bedfordshire. It is also found in the district of the Great Ouse, Bedfordshire.

Physicochemical. - It is a mineral of the class of arsenates. It is also found in the district of the Great Ouse, Bedfordshire. It is also found in the district of the Great Ouse, Bedfordshire.

Remarks. - It is a mineral of the class of arsenates. It is also found in the district of the Great Ouse, Bedfordshire. It is also found in the district of the Great Ouse, Bedfordshire.

Corrosion. - It is a mineral of the class of arsenates. It is also found in the district of the Great Ouse, Bedfordshire. It is also found in the district of the Great Ouse, Bedfordshire.

DUFRENITE. *Arzuffite*.

Monoclinic. Crystals rare, small, but distinct. Usually massive, in nodules or druse fibrous with druse surface.

Color. - Dull, perfect. H = 3.5-4. G = 3.2-3.4. Luster silky, weak. Color bluish-green, emerald-green or bluish green when in exposure to yellow heat or air. Str. a weak green. Sp. gr. 1.84. $\alpha = 1.84$, $\beta = 1.85$, $\gamma = 1.88$. 2V small to 18. Very strong dispersion. Strongly pleochroic. Yellowish to green and dark red-brown. At times shows zonal structure with varying degrees of characters.

Comp. - Dicalcium phosphate $(\text{Ca})_2 (\text{P})_2 (\text{O})_7$. Phosphorus pentoxide 27.5, iron sesquioxide 62.0, water 10.5 = 100.

Pyr., etc. Same as for iron phosphate. It is also found in the district of the Great Ouse, Bedfordshire. It is also found in the district of the Great Ouse, Bedfordshire.

Obs. - It is a mineral of the class of phosphates. It is also found in the district of the Great Ouse, Bedfordshire. It is also found in the district of the Great Ouse, Bedfordshire.

Dussertite. — $\text{Ca}_2(\text{AsO}_4)_2 \cdot 3\text{H}_2\text{O} \cdot (\text{OH})$. Hexagonal or hexagonal rhombohedral. In small crystals, tabular parallel to 0001. $H = 3.5$. $G = 3.75$. Color green. In small, $n = 1.87$, $\alpha = 1.85$. Pleochroic in shades of greenish yellow. Occurs as crystals on quartz at Djoudi Dehar northeast of Haouassa Mekko line, Constantine, Algeria.

Allactite. $\text{Mn}_2\text{As}_2\text{O}_7 \cdot 4\text{Mn}(\text{OH})_2$. Monoclinic. In small brownish red prismatic crystals or tabular. $H = 3.5$. Several inclusions of cleavage. $H = 4.5$. $G = 3.8$. Fast to at 6. Optically — Ax pl. \perp (010) for blue, (010) for red and yellow. $X \wedge$ axis = 50° . $\alpha = 1.75$, $\beta = 1.78$, $\gamma = 1.78$. 2V very small. Dispersion very strong, $\rho > \alpha$. In Vermland, Sweden, at the Moss mine, Norrmark, and a. Långbanhyttan.

Synadelphite. $2 \text{Al} \cdot \text{Mn} \cdot \text{AsO}_4 \cdot 5 \text{Mn} \cdot (\text{OH})_2$. Monoclinic. In prismatic crystals, also in groups. $H = 4.5$. $G = 3.6$. Easily fusible. Color brownish black to black. Optically — Ax pl. \perp (010). $X \wedge$ axis = 46° . $\alpha = 1.86$, $\beta = 1.87$, $\gamma = 1.90$. 2V small. From the Moss mine, Norrmark, Vermland, Sweden.

Adolophite. $3 \text{Mn} \cdot 2 \text{Mn} \cdot \text{Al} \cdot \text{As}_2\text{O}_7 \cdot 5 \text{H}_2\text{O}$. Probably orthorhombic. In tabular elongated crystals. Conchoidal fracture. $G = 3.573$. Color dark reddish-brown to brownish black. Optically — $\alpha = 1.7244$, $\beta = 1.7403$. 2V very small. From Långbanhyttan, Vermland, Sweden.

Fluikite. $\text{Mn}_2\text{As}_2\text{O}_7 \cdot 2 \text{Mn}(\text{OH})_2$. In minute orthorhombic crystals, tabular. 0001 groups in center of aggregates. $H = 4.5$. $G = 3.87$. Easily fusible. Color greenish brown. Optically — Ax pl. 001. $Z =$ axis. $\alpha = 1.74$, $\beta = 1.80$, $\gamma = 1.84$. 2V large. Pleochroic. $X =$ pale brownish green, $Y =$ yellowish green, $Z =$ orange-brown. From the Harnäs mine, Paparö, near Pernery, Vermland, Sweden.

Hemimorphite. Perhaps $\text{Al} \cdot \text{Mn} \cdot \text{As}_2\text{O}_7 \cdot 4 \text{Mn}(\text{OH})_2$. In rhombohedral crystals. Good cleavage, perfect. $H = 3.6$. $G = 3.4$. Lustrous. Color brownish red, dark on the surface. Optically — $\alpha = 1.713$, $\beta = 1.74$. Also at same locality with musc. 2V from the Moss mine, Norrmark, Vermland, Sweden.

Reteite. Various amounts of the vitreous earths, manganese and calcium. In orthorhombic crystals. $H = 4$. $G = 4.15$. Lustrous. Color chocolate to chestnut brown. Optically — Ax pl. \perp (010). $Z =$ axis. $\alpha = 1.77$, $\beta = 1.88$, $\gamma = 1.90$. 2V large. Pleochroic. $X =$ colorless, $Y =$ pure yellow-brown, $Z =$ red-brown. From the Moss mine, Norrmark, Vermland, Sweden.

Arzenoptite. Perhaps $\text{Ba}_2\text{H}_2\text{O} \cdot \text{As}_2\text{O}_7 \cdot \text{As}_2\text{O}_7$. $R = \text{Mn}$ (Ca, also Fe, Mg, $R = \text{Mn}$, also Fe) (rhombohedral with rhombohedral cleavage). Musc. v. cleavable. $H = 3.5$. Easily fusible. Color brownish red. Optically — $\alpha = 1.791$, $\beta = 1.80$. Sometimes lustrous but more α . X axis at the S. end, near Örebro, Sweden, with rhomboic in crystalline masses.

Manganostibite. $\text{Mn}_2\text{Sb}_2\text{O}_7$. Monoclinic. In small rods as fibers and embedded groups. Cleavage (01), perfect. In small. Color black. Optically — Ax pl. \perp (01). $Z =$ elongation. $\alpha = 1.62$, $\beta = 1.65$, $\gamma = 1.60$. 2V small. Strongly pleochroic. $X =$ redish brown, $Y = Z =$ almost colorless. From Norrmark, Vermland, Sweden. Hemimorphite is found only at the S. end, near Örebro, Sweden.

Arzenite. Same type as arsenate, $\text{H}_2\text{As}_2\text{O}_7$. Monoclinic. In small tabular crystals. Cleavage (01), poor. $H = 3$. $G = 6.4$. Easily fusible. Color brownish yellow. Optically — $\alpha = 2.14$, $\beta = 2.18$, $\gamma = 2.18$. 2V = 44° . Dispersion, $\rho < \alpha$. From Schneeberg, Saxony.

C. Normal Hydrous Phosphates, etc.

The only important group among the normal hydrous phosphates is the monoclinic **LEVANTITE GROUP**.

Struvite. $\text{NH}_4\text{MgPO}_4 \cdot 6\text{H}_2\text{O}$. In orthorhombic hemimorphic crystals (Fig. 342 p. 145). Cleavage (01) perfect. $G = 3.0$. Good. $H = 2$. $G = 1.7$. Fast to at yellowish. Optically — Ax pl. 100. $Z =$ axis. $\alpha = 1.495$, $\beta = 1.416$, $\gamma = 1.504$. 2V = 60° . Strong dispersion, $\rho < \alpha$. Struvite is formed where magnesium solution act upon a phosphate in the presence of ammonium. Such conditions may exist in lakes of gypsum etc. after a long time, and also in the soil for a long period.

Colophanite. Essentially $\text{Ca}_2\text{H}_2\text{O} \cdot (\text{CO}_3)_{200000}$ variable, especially as to water content. Also contains small amounts of calcium carbonate, fluoride, sulphate, etc.

Amorphous. In layers resembling gypsum or opal. Conchoidal fracture. $H = 2-5$. $G = 2.6-2.9$. Diffusely fibrous. Colorless or snow-white. Isotropic. $n = 1.57-1.63$.
Hydroxylapatite is usually found in coral limestones which have been covered by beds of gypsum. From the island of Soudra in the West Indies, having been formed in the elevated coral reef by migration of the salts from the overlying gypsum. Monite is similar from the islands Mona and Mona in the West Indies, where it is associated with monite $HCaPO_4$, which occurs in yellowish white crystalline crystals, is optically + with $d = 1.518$. Also similarly found in various localities in the northern Pacific Ocean. Material apparently identical with colophonite found in nodules in a sandy mud near Grod, Iceland, has been named *grodmonite*. Colophonite is probably an important constituent of the phosphorites described under apatite p. 704.
Phosphogypsum $Mg_2P_2O_7 \cdot 4Ca_3P_2O_8 \cdot Ca_3P_2O_8$? Massive, earthy. Color snow-white, dull. From the West Indies.

Hopseite. $Zn_3P_4O_{14}H_2O$. Orthorhombic. In minute prismatic crystals. Also in reniform masses. Three cleavages α, β, γ perfect, β 010 good, α 001 poor. $H = 3-2$. $G = 3$. Diffusely fibrous. Color grayish white. Crystals from Broken Hill show interlocking of two modifications, α and β hopseite which have the same composition but differ in their optical characters. Both varieties are optically - and $X = b$ axis. In α -hopseite $Z = c$ axis, while in β -hopseite $Z = a$ or c axis. Indices for α -hopseite are, $\alpha = 1.572$, $\beta = 1.591$, $\gamma = 1.592$. $2V = 38^\circ$. In β -hopseite $\alpha = 1.574$, $\beta = 1.582$, $\gamma = 1.592$. $2V = 25^\circ$ very small. Found in rare line in calc spar at the mine near M. rousset, Roumou in L. or Alençon, southwest of Azay le Chapeau. Also found at Salmo, Nelson mining district, British Columbia, (Chapman).

Phosphophyllite. — Essentially a zinc phosphate with composition similar to hopseite, $H_2PO_4 \cdot 4H_2O$. Monoclinic or triclinic with angles similar to those of hopseite. Cleavages 100 perfect, 010 102 distinct. $H = 3$. $G = 3.1$. Colorless to pale blue-green. Optically -. Ax. pl. 1 010. $Z = b$ axis. $Y \wedge$ axis $= 90^\circ$. $\alpha = 1.595$, $\beta = 1.616$, $\gamma = 1.616$. $2V = 60^\circ$. From Hagendorf near Pilsen in the Oberpfalz Bavaria.

Parahopseite. $Zn_3P_4O_{14}H_2O$. Same as for hopseite. Triclinic. In tabular crystals 100 with distinct striations (twined or 100). Good cleavages 0 100. $H = 3$. $G = 3.1$. Same form as hopseite. Optically +. $\alpha = 1.614$, $\beta = 1.625$, $\gamma = 1.637$. $2V$ large. Found at Broken Hill, Rhodesia, also from Salmo, Nelson mining district, British Columbia.

Dickinsonite. (Mg,Fe,Cu,H_2O) with $R = Mn, Fe, Na$, chiefly also Ca, K, Li . Monoclinic. Tabular pseudorhombic crystals commonly twinned to 100. Cleavage 001 perfect. $G = 2.4$. Fibrous and in color close to a green glass-green. Optically -. Ax. pl. 1 001. $X = b$ axis. $\alpha = 1.635$, $\beta = 1.662$. $2V$ very small to large. Strong dispersion, $n > v$. From Deuchville, Fairfield Co., Connecticut. Also from Point of Anse-au-Loup, Martinique.

Feldsparite. For much as for dickinsonite, but differing in crystal form. Monoclinic, (rare form on schists). Basic cleavage. In granular crystalline masses. $H = 4.5$. $G = 3.3$. Fibrous and fibrous. Color was greenish yellow to red-brown. Optically -. $\alpha = 1.672$, $\beta = 1.672$, $\gamma = 1.678$. $2V$ small. Occurs sparingly at Deuchville, Fairfield Co., Connecticut.

The three following species are related in composition and may be in crystalline form.
Roschite. (Mg,Fe,Cu,H_2O) Triclinic. In small crystals, often in 100 and spherical aggregates. Lateral twinning. One cleavage perfect. $H = 3.5$. $G = 2.5-3.4$. Fibrous and fibrous. Color light to dark reddish. Optically +. $X \perp$ cleavage. $\beta = 1.725$. Strong dispersion, $n > v$. From Deuchville, Fairfield Co., Connecticut.

Brasillite. (Mg,Fe,Cu,H_2O) Monoclinic. In prismatic crystals. Crystals often twinned in radiating groups. Cleavage 0 100. $H = 3.5$. $G = 3.7$. Fibrous. Colorless to white. Optically +. Ax. pl. 1 010. $\alpha = 1.700$, $\beta = 1.711$, $\gamma = 1.724$. From the Bergs mine, Pärberg near Persens, Vermland, Sweden.

Fairfieldite. A hyaline phosphate of calcium and magnesium, $(Ca,Mg)P_2O_7 \cdot 2H_2O$. Triclinic. In prismatic crystals usually in luster or fibrous crystalline aggregates. Cleavages 010 perfect, 100 good. $H = 3.5$. $G = 3$. Fibrous. Color white to greenish white to pure straw yellow. Optically +. $\alpha = 1.638$, $\beta = 1.644$, $\gamma = 1.654$. $2V$ large. Dispersion $n > v$. From Branchville, Fairfield Co., Connecticut. Also from near Zwettau, Bavaria. *Leucocyanite*. Recently found in Maine at Rockfield, Concord Co., and at Pound, Antrim Co.

Rhodonite, with magnetite crystals. This occurrence may, however, be of anakawite, etc.

| | | | | |
|------------|---------------------------------|---------------------------------|----------------------------------|----------------------------------|
| Arakawaste | K. med. 6 - 40 g. 22nd Feb 1970 | M. med. 6 - 40 g. 22nd Feb 1970 | Bl. med. 6 - 40 g. 22nd Feb 1970 | Bl. med. 6 - 40 g. 22nd Feb 1970 |
| Arakawaste | K. med. 6 - 40 g. 22nd Feb 1970 | M. med. 6 - 40 g. 22nd Feb 1970 | Bl. med. 6 - 40 g. 22nd Feb 1970 | Bl. med. 6 - 40 g. 22nd Feb 1970 |
| Arakawaste | K. med. 6 - 40 g. 22nd Feb 1970 | M. med. 6 - 40 g. 22nd Feb 1970 | Bl. med. 6 - 40 g. 22nd Feb 1970 | Bl. med. 6 - 40 g. 22nd Feb 1970 |

WATFLLITE

Orthorhombic. Axes $a:b:c = 0.5520:1:0.4067$. Crystal rare. Usually in aggregates, hemispherical or globular with crystalline surface and radiated structure.

Coating $f = 0.1$ and $h = 10$ rather poor. Fracture motion is subcritical. Figure 11: $\dot{U} = 4.2 \times 10^{-4}$ J/s, $\dot{\gamma} = 2.5 \times 10^{-4}$ 1/s. Further vitrification leading to partly dark regions. Under white passing into yellow, green, gray, brown, and black. Struck with a base coat. $\dot{U} = 1.3 \times 10^{-4}$ J/s, $\dot{\gamma} = 1.3 \times 10^{-4}$ 1/s. $Z = 0.4 \times 10^{-4}$ s, $\alpha = 1.7 \times 10^{-4}$ 1/s, $\beta = 1.3 \times 10^{-4}$ 1/s, $\gamma = 1.3 \times 10^{-4}$ 1/s.

Comp - $4\text{Al}(\text{OH})_3 + 2\text{Al}(\text{OH})_3 + 4\text{H}_2\text{O} = \text{Phosphorus pentoxide}$ and $2\text{H}_2\text{O}$
350. water $\Delta G = 100$ { water is sometimes present, 10 to 2 percent

[illegible]

1. The first step is to identify the problem or goal. This involves understanding the current situation and what needs to be achieved.

[illegible]

TURQUIS. 1472. — 1897.

Truering. Crystals minute and ranges, not in case of *halimolite* with which they are sometimes associated. Crystals of *halimolite* are usually from 1 mm. long, and some crystals or aggregates of crystals are 1 mm. or more in diameter. Also in rolled masses.

[illegible]

Comp A lithium phosphate of $\text{Li}_2\text{P}_2\text{O}_7$ and copper(II) sulfate
 $2\text{P}_2\text{O}_5 \cdot 6\text{H}_2\text{O}$ in part as $\text{H}_2\text{C}_2\text{O}_4 \cdot \text{Al}(\text{H}_2\text{O})_2 \cdot \text{PO}_3\text{Na}$. Phosphorus pentoxide
 per Al 12 atoms, total copper oxide 0.77, water 10.47 = 100.

For $\alpha \in \mathbb{C}$ and $\beta \in \mathbb{R}$, the α -th and β -th moments require such order in the set $\{d, \alpha, \beta\}$.

[illegible]

shows the same green, mottled with hydrous iron, as the color is at first blue, copper.

Obs. — The green is a very common color in the rocks of the region, and is often found in the same places as the blue. It is often found in the same places as the blue, and is often found in the same places as the blue.

portions of a porphyry
of the Al-Milani.

The porphyry is a very common rock in the region, and is often found in the same places as the blue.

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Sturges has been found in the Coosa coal field of Alabama and from Chambers, Carter Co., Tenn.

Curculacitrate = $3\text{Al}(\text{OH})_3 \cdot 2\text{H}_2\text{O}_2 \cdot 6\text{H}_2\text{O}$ (pyrocuracitric acid hydrate) Molecular weight = 1000.0
 1 mole curculacitrate contains 18 moles water. Water content = 18.00%
 1 mole curculacitrate contains 18 moles water. Water content = 18.00%
 1 mole curculacitrate contains 18 moles water. Water content = 18.00%
 1 mole curculacitrate contains 18 moles water. Water content = 18.00%

Augelite $2\text{Ag}_2\text{S} \cdot 3\text{Ag}_2\text{S}_2\text{O}_3$ $\text{Ag}_2\text{S} \cdot 1.5\text{Ag}_2\text{S}_2\text{O}_3$ $\text{Ag}_2\text{S} \cdot 0.75\text{Ag}_2\text{S}_2\text{O}_3$ $\text{Ag}_2\text{S} \cdot 0.375\text{Ag}_2\text{S}_2\text{O}_3$ $\text{Ag}_2\text{S} \cdot 0.1875\text{Ag}_2\text{S}_2\text{O}_3$ $\text{Ag}_2\text{S} \cdot 0.09375\text{Ag}_2\text{S}_2\text{O}_3$ $\text{Ag}_2\text{S} \cdot 0.046875\text{Ag}_2\text{S}_2\text{O}_3$ $\text{Ag}_2\text{S} \cdot 0.0234375\text{Ag}_2\text{S}_2\text{O}_3$ $\text{Ag}_2\text{S} \cdot 0.01171875\text{Ag}_2\text{S}_2\text{O}_3$ $\text{Ag}_2\text{S} \cdot 0.005859375\text{Ag}_2\text{S}_2\text{O}_3$ $\text{Ag}_2\text{S} \cdot 0.0029296875\text{Ag}_2\text{S}_2\text{O}_3$ $\text{Ag}_2\text{S} \cdot 0.00146484375\text{Ag}_2\text{S}_2\text{O}_3$ $\text{Ag}_2\text{S} \cdot 0.000732421875\text{Ag}_2\text{S}_2\text{O}_3$ $\text{Ag}_2\text{S} \cdot 0.0003662109375\text{Ag}_2\text{S}_2\text{O}_3$ $\text{Ag}_2\text{S} \cdot 0.00018310546875\text{Ag}_2\text{S}_2\text{O}_3$ $\text{Ag}_2\text{S} \cdot 0.000091552734375\text{Ag}_2\text{S}_2\text{O}_3$ $\text{Ag}_2\text{S} \cdot 0.0000457763671875\text{Ag}_2\text{S}_2\text{O}_3$ $\text{Ag}_2\text{S} \cdot 0.00002288818359375\text{Ag}_2\text{S}_2\text{O}_3$ $\text{Ag}_2\text{S} \cdot 0.000011444091796875\text{Ag}_2\text{S}_2\text{O}_3$ $\text{Ag}_2\text{S} \cdot 0.0000057220458984375\text{Ag}_2\text{S}_2\text{O}_3$ $\text{Ag}_2\text{S} \cdot 0.00000286102294921875\text{Ag}_2\text{S}_2\text{O}_3$ $\text{Ag}_2\text{S} \cdot 0.000001430511474609375\text{Ag}_2\text{S}_2\text{O}_3$ $\text{Ag}_2\text{S} \cdot 0.0000007152557373046875\text{Ag}_2\text{S}_2\text{O}_3$ $\text{Ag}_2\text{S} \cdot 0.00000035762786865234375\text{Ag}_2\text{S}_2\text{O}_3$ $\text{Ag}_2\text{S} \cdot 0.000000178813934326171875\text{Ag}_2\text{S}_2\text{O}_3$ $\text{Ag}_2\text{S} \cdot 0.0000000894069671630859375\text{Ag}_2\text{S}_2\text{O}_3$ $\text{Ag}_2\text{S} \cdot 0.00000004470348358154296875\text{Ag}_2\text{S}_2\text{O}_3$ $\text{Ag}_2\text{S} \cdot 0.000000022351741790771484375\text{Ag}_2\text{S}_2\text{O}_3$ $\text{Ag}_2\text{S} \cdot 0.0000000111758708953857421875\text{Ag}_2\text{S}_2\text{O}_3$ $\text{Ag}_2\text{S} \cdot 0.00000000558793544769287109375\text{Ag}_2\text{S}_2\text{O}_3$ $\text{Ag}_2\text{S} \cdot 0.000000002793967723846435546875\text{Ag}_2\text{S}_2\text{O}_3$ $\text{Ag}_2\text{S} \cdot 0.0000000013969838619232177734375\text{Ag}_2\text{S}_2\text{O}_3$ $\text{Ag}_2\text{S} \cdot 0.00000000069849193096160888671875\text{Ag}_2\text{S}_2\text{O}_3$ $\text{Ag}_2\text{S} \cdot 0.000000000349245965480804443359375\text{Ag}_2\text{S}_2\text{O}_3$ $\text{Ag}_2\text{S} \cdot 0.0000000001746229827404022216796875\text{Ag}_2\text{S}_2\text{O}_3$ $\text{Ag}_2\text{S} \cdot 0.00000000008731149137020111083984375\text{Ag}_2\text{S}_2\text{O}_3$ $\text{Ag}_2\text{S} \cdot 0.000000000043655745685100555419921875\text{Ag}_2\text{S}_2\text{O}_3$ $\text{Ag}_2\text{S} \cdot 0.0000000000218278728425502777099609375\text{Ag}_2\text{S}_2\text{O}_3$ $\text{Ag}_2\text{S} \cdot 0.00000000001091393642127513885498046875\text{Ag}_2\text{S}_2\text{O}_3$ $\text{Ag}_2\text{S} \cdot 0.000000000005456968210637569427490234375\text{Ag}_2\text{S}_2\text{O}_3$ $\text{Ag}_2\text{S} \cdot 0.0000000000027284841053187847137451171875\text{Ag}_2\text{S}_2\text{O}_3$ $\text{Ag}_2\text{S} \cdot 0.00000000000136424205265939235687255859375\text{Ag}_2\text{S}_2\text{O}_3$ $\text{Ag}_2\text{S} \cdot 0.000000000000682121026329696178436279296875\text{Ag}_2\text{S}_2\text{O}_3$ $\text{Ag}_2\text{S} \cdot 0.0000000000003410605131648480892181396484375\text{Ag}_2\text{S}_2\text{O}_3$ $\text{Ag}_2\text{S} \cdot 0.00000000000017053025658242404460906982421875\text{Ag}_2\text{S}_2\text{O}_3$ $\text{Ag}_2\text{S} \cdot 0.000000000000085265128291212022304534912209375\text{Ag}_2\text{S}_2\text{O}_3$ $\text{Ag}_2\text{S} \cdot 0.0000000000000426325641456060111522674561046875\text{Ag}_2\text{S}_2\text{O}_3$ $\text{Ag}_2\text{S} \cdot 0.00000000000002131628207280300557613372805234375\text{Ag}_2\text{S}_2\text{O}_3$ $\text{Ag}_2\text{S} \cdot 0.000000000000010658141036401502788066864026171875\text{Ag}_2\text{S}_2\text{O}_3$ $\text{Ag}_2\text{S} \cdot 0.00000000000000532907051820075139403343200130859375\text{Ag}_2\text{S}_2\text{O}_3$ $\text{Ag}_2\text{S} \cdot 0.000000000000002664535259100375697016716000654296875\text{Ag}_2\text{S}_2\text{O}_3$ $\text{Ag}_2\text{S} \cdot 0.0000000000000013322676295501878485083580003271484375\text{Ag}_2\text{S}_2\text{O}_3$ $\text{Ag}_2\text{S} \cdot 0.00000000000000066613381477509392425417900016357421875\text{Ag}_2\text{S}_2\text{O}_3$ $\text{Ag}_2\text{S} \cdot 0.000000000000000333066907387546962127089500081787109375\text{Ag}_2\text{S}_2\text{O}_3$ $\text{Ag}_2\text{S} \cdot 0.0000000000000001665334536937734810635447500408935546875\text{Ag}_2\text{S}_2\text{O}_3$ $\text{Ag}_2\text{S} \cdot 0.00000000000000008326672684688674053177237500204467734375\text{Ag}_2\text{S}_2\text{O}_3$ $\text{Ag}_2\text{S} \cdot 0.000000000000000041633363423443370265886187501022338671875\text{Ag}_2\text{S}_2\text{O}_3$ $\text{Ag}_2\text{S} \cdot 0.00000000000000002081668171172168513294309375005111693546875\text{Ag}_2\text{S}_2\text{O}_3$ $\text{Ag}_2\text{S} \cdot 0.000000000000000010408340855860842566471546875002555967734375\text{Ag}_2\text{S}_2\text{O}_3$ $\text{Ag}_2\text{S} \cdot 0.0000000000000000052041704279304212782237734375001$

The three following *Leptothorax* species are found in the Westland mts. near Nauru
 were: *L. ocellatus*, *L. niger* and *L. swinhonis*.

From 1.57 g (0.01 mole) of $(\text{C}_6\text{H}_5)_2\text{C}(\text{CH}_3)_2$ and 1.00 g (0.01 mole) of $\text{C}_6\text{H}_5\text{MgBr}$ in 10 ml of ether, 0.10 g (2%) of compound 1 was obtained. Compound 1 is a grayish solid, m.p. 100°C.

Preparation: 131g (0.5 mol) SnCl_4 , 10g (0.5 mol) H_2O , 10g (0.5 mol) H_2SO_4 . Compact, unimolally cleavable. $G = 3.10$. Colorless crystals. Practically identical with butyltin.

See entry $P(1), A(2), M(1), n(1), d(1)$, etc.; formula doubtful. Manganese $n = 300$
(Calc. mol. wt. 100).

MINNESOTA.—For this winter have been described a series of hybrid albatrosses, though they are in evidence in the south of the State, but are not abundant. A number of the hybrid species taken in New South Wales. The most common of

Vashkyite, Ag_3S , 3.06, 10.1, 1.56, $H = 2.5$, $d = 6.0$, color white, streak white, translucent when crushed, lustrous, $n = 1.56$, fibers 7 from mine near Vashky, near South in Gromat in Shikha, Chukotka, U.S.S.R. Reported from near Manhaton, Nye Co., Nevada.

PHARMACONSIDERITE

Pseudocubic-tetrahedral. Commonly in cubes, also tetrahedral.
Rarely granular.

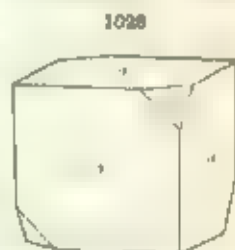
Clear (at 100) imperfect. Fracture uneven. Rather brittle. H = 2.5. G = 2.0-3. Luster adamantine to glassy, not very distinct. Color olive, gray or original green-yellowish brown, honey-yellow. Streak green to brown, yellow, pale. Subtranslucent to subtranslucent. Not isotropic, $n = 1.603$. At ordinary temperatures anisotropic, showing crystal division into hexagonal segments. Usually optically very strong. $\rho = 2.0$.

Comp. Perhaps 6H₂O, 2H₂O, 12H₂O = Arsenic pentoxide 43.1, arsenic trioxide 40.0, water 16.9 = 100. Some varieties contain Fe₂O₃.

Per etc. *Notre* has four occurrences

[illegible]

Lucaninone, $\text{C}_{12}\text{H}_{14}\text{O}_4$, $\text{M} = 214$, Monoclinic. Occurs in small green transparent crystals. mp 100°C. $d_4^{20} = 1.160$, $n_D^{20} = 1.467$, $n_D^{25} = 1.465$. From near Frons, Carinthia. *Lechnerite*, occurs as small green crystals from Hagerdorf, Bavaria, is closely similar to lucaninone and probably identical with it.



Cacorenite.— $\text{FePO}_4 \cdot \text{FeOH} \cdot 4\frac{1}{2}\text{H}_2\text{O}$. Hexagonal. In radiated tufts of a yellow or brownish color. $H = 3.5$. $G = 3.4$. From the Opticway, $\mu = 1.590-1.585$, $\alpha = 1.584-1.585$. Occurs in the ochraceous clay in Illinois near St. Bernard and at Zions near Carthage, where a small amount of hematite is also present. A few pieces are made in the Clinchburg near Cassin, in Illinois, and in Washington in the same locality, also at West in Hesse-Nassau. In the latter states from the water of an iron mine at Perryville.

Xanthoxite. $\text{H}_2\text{Fe}_2(\text{SiO}_3)_2 \cdot 2\text{H}_2\text{O}$. Monoclinic. $\mu = 1.560-1.555$. From Hahnemann, Hesse-Nassau. Near Hahnemann.

Bertrandite. $2\text{FePO}_4 \cdot 2\text{FeOH} \cdot 9\frac{1}{2}\text{H}_2\text{O}$. Monoclinic. Occurs only in the form of a radiated aggregate. $H = 3.5$. $G = 3.4$. From the Opticway, $\mu = 1.590-1.585$, $\alpha = 1.584-1.585$. Occurs in the ochraceous clay in Illinois near St. Bernard and at Zions near Carthage, where a small amount of hematite is also present. A few pieces are made in the Clinchburg near Cassin, in Illinois, and in Washington in the same locality, also at West in Hesse-Nassau. In the latter states from the water of an iron mine at Perryville.

Kochschornitzite, Oxyschornitzite, are other hydrated ferric phosphates.

CHILDRENITE.

Orthorhombic. Axes $a : b : c = 0.7780 : 1 : 0.52575$.

μ_{100} , $110 \wedge 110 = 75^\circ 40'$

μ_{100} , $110 \wedge 110 = 105^\circ 0'$

μ_{100} , $110 \wedge 110 = 30^\circ 47'$

μ_{100} , $110 \wedge 110 = 40^\circ 47'$

Only known in crystals. Cleavage $\{100\}$ imperfect. Fracture uneven. $H = 4.5-5$. $G = 3.18-3.24$. Luster vitreous to resinous. Color yellowish white, pale yellowish brown, brownish black. Streak white to yellowish. Translucent. $2\theta = 74^\circ$. Optic axes. Ax. pl. $\{100\}$. $A = b$ axis. $\alpha = 1.613$, $\beta = 1.678$, $\gamma = 1.684$. $2V = 45^\circ$. Dispersion strong $\alpha > \gamma$.

Comp. In general $\text{AlPO}_4 \cdot \text{FeOH} \cdot \text{H}_2\text{O}$. Phosphorus pentoxide 30.0, aluminum 22.2, iron peroxide 34.3, water 17.6 = 100. Manganese replaces part of the iron and it hence gradates into eschscholtzite.

Pyrr., etc.—In the closed tube gives off a little water. B.B. analysis, but a reaction takes place. The liquid is black, brown, green, the flame blue green. Reaction in closed tube black and blackish green. Water is given off a little. For manganese. With strong acid it gives phosphoric acid for iron and manganese. Soluble in hydrochloric acid.

Obs. Found in the formation near Ehrenfriedersdorf, Saxony. From near Tarnobrzeg, Poland. Also in the formation near Ehrenfriedersdorf, Saxony. From near Tarnobrzeg, Poland.

Krausbergite. $\text{FePO}_4 \cdot \text{FeOH} \cdot \text{H}_2\text{O}$. Orthorhombic. Cleavage $\{100\}$. White, yellow. $H = 4.5-5$. $G = 3.18-3.24$. Luster vitreous to resinous. Color white to yellowish. Translucent. $2\theta = 74^\circ$. Optic axes. Ax. pl. $\{100\}$. $A = b$ axis. $\alpha = 1.613$, $\beta = 1.678$, $\gamma = 1.684$. $2V = 45^\circ$. Dispersion strong $\alpha > \gamma$.

Eschscholtzite. $\text{FePO}_4 \cdot \text{FeOH} \cdot \text{H}_2\text{O}$. Orthorhombic. Cleavage $\{100\}$. $H = 4.5-5$. $G = 3.18-3.24$. Luster vitreous to resinous. Color white to yellowish. Translucent. $2\theta = 74^\circ$. Optic axes. Ax. pl. $\{100\}$. $A = b$ axis. $\alpha = 1.613$, $\beta = 1.678$, $\gamma = 1.684$. $2V = 45^\circ$. Dispersion strong $\alpha > \gamma$.

Maraphite. $\text{FePO}_4 \cdot \text{FeOH} \cdot \text{H}_2\text{O}$. Orthorhombic. In slender prismatic crystals. $H = 4.5-5$. $G = 3.18-3.24$. Luster vitreous. Color dark. Near the formation. $H = 4.5-5$. $G = 3.18-3.24$. Luster vitreous. Color dark. Near the formation. $H = 4.5-5$. $G = 3.18-3.24$. Luster vitreous. Color dark. Near the formation.

Xanthoxite. $\text{H}_2\text{Fe}_2(\text{SiO}_3)_2 \cdot 2\text{H}_2\text{O}$. Monoclinic. In the form of a radiated aggregate. $H = 3.5$. $G = 3.4$. From the Opticway, $\mu = 1.590-1.585$, $\alpha = 1.584-1.585$. Occurs in the ochraceous clay in Illinois near St. Bernard and at Zions near Carthage, where a small amount of hematite is also present. A few pieces are made in the Clinchburg near Cassin, in Illinois, and in Washington in the same locality, also at West in Hesse-Nassau. In the latter states from the water of an iron mine at Perryville.

Calcioferite. $\text{Ca Fe}_2(\text{PO}_4)_2 \cdot 4\text{H}_2\text{O}$, $\text{H}_2\text{Si}_2\text{O}_7$? Monoclinic? Occurs in yellow to green nodules (Chavaguo (001), variety H = 2.5, $\epsilon = 2.2$). Easily fusible. Nearly vertical optical axis. $n = 1.51-1.58$. From the lavas of Battenberg, Nassau.

Baricite. Perhaps $\text{CaFe}_2(\text{PO}_4)_2 \cdot 4\text{H}_2\text{O}$, $\text{H}_2\text{Si}_2\text{O}_7$? Amorphous. Baricite massive (estimated H = 2.5, $\epsilon = 2$). Fusible. Color reddish brown. From the lavas of Battenberg, Nassau. In Bohemia of Czechoslovakia in Namur near Liege, Belgium. Also from the lavas of Battenberg, Nassau. Reported from the Little Belt mts. of Montana under the name of baricite. (From the French phosphate deposits from the Belgian mts. of Namur in Belgium. From the French phosphate deposits from the Belgian mts. of Namur in Belgium.)

Baricite. A hydrothermal phosphate of ferric iron with calcium and silicon. Amorphous. In nodules and decussate in the phosphate deposits. From the French phosphate deposits from the Belgian mts. of Namur in Belgium. From the French phosphate deposits from the Belgian mts. of Namur in Belgium.

Baricite. Perhaps $\text{Fe}_2(\text{PO}_4)_2 \cdot 4\text{H}_2\text{O}$, $\text{H}_2\text{Si}_2\text{O}_7$? Massive, compact or foliated. Color yellow. From Michelle, near Verviers, Liege, Belgium.

LIROCONITE.

Monoclinic. Axes $a:b:c = 1.7191:1:1.0808$, $\beta = 88^\circ 53'$

$m\mu$, $10^\circ \wedge 170^\circ = 105.49$ $m\mu$, $11^\circ \wedge 07^\circ = 41.60$
 ϵ , $011^\circ \wedge 03^\circ = 118.29$ $m\mu$, $110^\circ \wedge 011^\circ = 45.24$

1029

Crystals resembling rhombic octahedrons. Rarely granular. Cleavage $m\mu 110^\circ$ and 011° indistinct. Fine laminae inclined to each other in series, section B = 2.25 , $\epsilon = 2.0$. Luster vitreous, changing to resinous. Color and streak sky-blue to very light green. Optically. Ax. pl. $1^\circ \wedge 0$, Z \wedge crystal = 25° , $n = 1.652$, $\beta = 1.652$, $\gamma = 1.675$, $2V = 67^\circ$



Comp. A hydrothermal phosphate of iron and copper, formula $\text{Fe}_2(\text{PO}_4)_2 \cdot 4\text{H}_2\text{O}$, $\text{H}_2\text{Si}_2\text{O}_7$. Anhydrous $\text{Fe}_2(\text{PO}_4)_2$, $30\% \text{H}_2\text{O}$, $20\% \text{H}_2\text{O}$. Anhydrous $\text{Fe}_2(\text{PO}_4)_2$, 28% , H_2O , 10% , cupric oxide 15% , water 21% = 100 . Phosphorus replaces part of the arsenic.

Pre. etc. In the nodules it gives much water and carbon dioxide. It is soluble in water, but not in dilute acids. It is soluble in water, but not in dilute acids. It is soluble in water, but not in dilute acids.

Obs. Found in the nodules of iron and copper, in the phosphate deposits. It is found in the nodules of iron and copper, in the phosphate deposits. It is found in the nodules of iron and copper, in the phosphate deposits.

Chenavite. $\text{Ca Fe}_2(\text{PO}_4)_2 \cdot 4\text{H}_2\text{O}$, $\text{H}_2\text{Si}_2\text{O}_7$? Crystalline. Massive to compact. H = 2.5, $\epsilon = 2$. Color brownish green to greenish yellow. $n = 1.55$. From the lavas of Battenberg, Nassau.

Hydrothermal. A hydrothermal phosphate of iron and copper. In the nodules of iron and copper, in the phosphate deposits. It is found in the nodules of iron and copper, in the phosphate deposits.

Comp. etc. $\text{Ca Fe}_2(\text{PO}_4)_2 \cdot 4\text{H}_2\text{O}$, $\text{H}_2\text{Si}_2\text{O}_7$? Compact, made up of very fine grains of $\text{Ca Fe}_2(\text{PO}_4)_2$. Color, translucent. Soluble in water. From the nodules of iron and copper, in the phosphate deposits.

Chalcocite. $\text{Cu}_2\text{Si}_2\text{O}_7 \cdot 2\text{P}_2\text{O}_5 \cdot 6\text{H}_2\text{O}$? Probably associated with copper. The color is greenish yellow to green. Cleavage 011° . H = 2.5, $\epsilon = 2.1$. Color and streak green. Optically. Ax. pl. $1^\circ \wedge 0$, Z \wedge crystal = 25° , $n = 1.652$, $\beta = 1.652$, $\gamma = 1.675$, $2V = 67^\circ$. From the nodules of iron and copper, in the phosphate deposits.

Obs. Found in the nodules of iron and copper, in the phosphate deposits.

Kochite. A hydrothermal phosphate of iron and copper. Amorphous. Massive. G = 2.5, $\epsilon = 2.1$. Color and streak green. Optically. Ax. pl. $1^\circ \wedge 0$, Z \wedge crystal = 25° , $n = 1.652$, $\beta = 1.652$, $\gamma = 1.675$, $2V = 67^\circ$. From the nodules of iron and copper, in the phosphate deposits.

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| Born in | Fredericksburg at Jacobus and Elizabeth
Schubert's house - Great the Lake | Originally found at |
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AUTONITE Line France.

September. In the tabular crystals, usually tetragonal in form and similar to siderite, a single also foliated mineral.

$H = 2.25$ $q_1 = 11$ Luster $f = 0.01$ nearly always on surface of
 Crater rim to sulphur-yellow brown yellowish brown to
 bluish opacely Ax ps b bluish $\lambda = 0.65$ $\alpha = 1.63$ $\beta =$
 1.575 $\gamma = 1.577$

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Section 1.1: Introduction to the study of the history of the world. The study of the history of the world is a branch of the social sciences. It is a branch of the social sciences that deals with the study of the history of the world. It is a branch of the social sciences that deals with the study of the history of the world. It is a branch of the social sciences that deals with the study of the history of the world.

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Pyritic iron ore is a common mineral in the earth's crust. It is a source of iron and sulfur. The ore is typically found in sedimentary basins and is often associated with coal. The iron is extracted from the ore through a process called blast furnacing, which produces pig iron. This pig iron is then refined into steel. Sulfur is also a byproduct of this process and is used in a variety of industrial applications, including the production of sulfuric acid and sulfur dioxide. The extraction of iron and sulfur from pyritic iron ore is a complex process that involves several steps, including mining, crushing, and refining. The resulting products are then used in a wide range of industries, from construction to manufacturing.

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Carnegie Appointments, 1901-1915, Vol. 2H-1. This volume of *Appointments* is the 20th in the series, and contains the appointments for the years 1901-1915. It is the first volume in the series to be published in a single volume, and is the first to be published in a single volume. It is the first volume in the series to be published in a single volume, and is the first to be published in a single volume.

There are three types of *Chrysomelidae* that are common in the garden. The most common is the *Chrysomelidae* beetle, which is a small, round, brown beetle with a yellowish-green tinge. It is found on the leaves of many plants, especially those in the *Chrysomelidae* family. The second type is the *Chrysomelidae* beetle, which is a small, round, brown beetle with a yellowish-green tinge. It is found on the leaves of many plants, especially those in the *Chrysomelidae* family. The third type is the *Chrysomelidae* beetle, which is a small, round, brown beetle with a yellowish-green tinge. It is found on the leaves of many plants, especially those in the *Chrysomelidae* family.

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Color black. In thin splinters red. Optically — $Ax, pl \parallel (010)$. $\rho = 1.08$. Pleochroism, rose-tinted to red above. From Braståter mine, North ark, Vermland, Sweden.

Dorbylite. — $As_2S_3 + 2FeS + 2FeS_2$. In prismatic or other big crystals. $H = 5$. $\rho = 4.53$. Color black. Semitranslucent, + indices $\pm 45-25^\circ$. From Triphy, near Ossa, Preto, Minas Geraes, Brazil.

Lewasite. — $Fe_2S_3 + 2FeS + 2FeS_2$. In minute yellow to brown isometric octahedra. $H = 5$. $\rho = 4.53$. $\alpha = 3.5$. $\beta = 4.9$. Easily fused. $n = 2.2$. From Triphy, near Ossa, Preto, Minas Geraes, Brazil.

Mauritite. — $As_2S_3 + 2FeS + 2FeS_2$. In dark and calcium related to lewasite. In dark brown prismatic crystals. $H = 5$. $\rho = 4.53$. Color black. Semitranslucent, + indices $\pm 45-25^\circ$. From Triphy, near Ossa, Preto, Minas Geraes, Brazil.

Arsenic. — As_2S_3 . In thin splinters red. Optically — $Ax, pl \parallel (010)$. $\rho = 1.08$. Pleochroism, rose-tinted to red above. From Braståter mine, North ark, Vermland, Sweden.

Phosphates or Arsenates with Carbonates, Sulphates, Borates

Destineite. — $2FeO \cdot 3H_2O, 2SO_4, 1H_2O$. In thin crystals. Optically — $Ax, pl \parallel (010)$. $H = 5$. $\rho = 4.53$. Color black. Semitranslucent, + indices $\pm 45-25^\circ$. From Triphy, near Ossa, Preto, Minas Geraes, Brazil.

Pittuite. — $As_2S_3 + 2FeS + 2FeS_2$. In dark and calcium related to lewasite. In dark brown prismatic crystals. $H = 5$. $\rho = 4.53$. Color black. Semitranslucent, + indices $\pm 45-25^\circ$. From Triphy, near Ossa, Preto, Minas Geraes, Brazil.

The following minerals form a group which shows certain relations to the Baudouite

Group, p. 711.

Swanhergite. — $28FeO \cdot 3Al_2O_3 \cdot 2SO_4 \cdot 1H_2O$. In thin crystals. Optically — $Ax, pl \parallel (010)$. $H = 5$. $\rho = 4.53$. Color black. Semitranslucent, + indices $\pm 45-25^\circ$. From Triphy, near Ossa, Preto, Minas Geraes, Brazil.

Takhtait. — $28FeO \cdot 3Al_2O_3 \cdot 2SO_4 \cdot 1H_2O$. In thin crystals. Optically — $Ax, pl \parallel (010)$. $H = 5$. $\rho = 4.53$. Color black. Semitranslucent, + indices $\pm 45-25^\circ$. From Triphy, near Ossa, Preto, Minas Geraes, Brazil.

Baudouite. — $21FeO \cdot 3Al_2O_3 \cdot 2SO_4 \cdot 1H_2O$. In thin crystals. Optically — $Ax, pl \parallel (010)$. $H = 5$. $\rho = 4.53$. Color black. Semitranslucent, + indices $\pm 45-25^\circ$. From Triphy, near Ossa, Preto, Minas Geraes, Brazil.

Boudouite. — $21FeO \cdot 3Al_2O_3 \cdot 2SO_4 \cdot 1H_2O$. In thin crystals. Optically — $Ax, pl \parallel (010)$. $H = 5$. $\rho = 4.53$. Color black. Semitranslucent, + indices $\pm 45-25^\circ$. From Triphy, near Ossa, Preto, Minas Geraes, Brazil.

Lewasite. — $21FeO \cdot 3Al_2O_3 \cdot 2SO_4 \cdot 1H_2O$. In thin crystals. Optically — $Ax, pl \parallel (010)$. $H = 5$. $\rho = 4.53$. Color black. Semitranslucent, + indices $\pm 45-25^\circ$. From Triphy, near Ossa, Preto, Minas Geraes, Brazil.

Lindackerite. — Perhaps $28FeO \cdot 3Al_2O_3 \cdot 2SO_4 \cdot 1H_2O$. Probably monoclinic. In rose-tinted to red above. Optically — $Ax, pl \parallel (010)$. $H = 5$. $\rho = 4.53$. Color black. Semitranslucent, + indices $\pm 45-25^\circ$. From Triphy, near Ossa, Preto, Minas Geraes, Brazil.

Lindackerite. — $3MgO \cdot B_2O_3 \cdot P_2O_5 \cdot 9H_2O$. Probably monoclinic. Crystals in six-sided plates. Optically — $Ax, pl \parallel (010)$. $H = 5$. $\rho = 4.53$. Color black. Semitranslucent, + indices $\pm 45-25^\circ$. From Triphy, near Ossa, Preto, Minas Geraes, Brazil.

VONKOVITE. $3\text{Fe,MgO} \cdot \text{B}_2\text{O}_3 \cdot \text{FeO} \cdot \text{FeCl}_2$. Similar to ludwigite with more ferrous iron. Hivera, Riverside Co., California.

Magnesian ludwigite. $\text{MgO} \cdot \text{B}_2\text{O}_3 \cdot \text{MgO} \cdot \text{FeO}$. The pyrophen end of the ludwigite series. Similar to ludwigite in crystal and optical properties. From Mountain Lake mine, south of Eggert, and Lake Co., Ind.

Pinakolite. $\text{Mg} \cdot \text{pyrophen} \cdot \text{Fe} \cdot \text{MgO} \cdot \text{B}_2\text{O}_3 \cdot \text{MnO} \cdot \text{MnO}_2$. Orthorhombic. In small fragments in white or cream-colored clay. $H = 6$, $G = 5.5$. Luster vitreous. For loose specimens. $Ax = 0.01$, $B = 0.01$, $C = 0.01$, $a = 0.01$, $b = 0.01$, $c = 0.01$. $2V = 34^\circ$. From Langlands Pass, Vermilion, Nevada.

Nordenskiöldine. A calcium titan borate, $\text{CaSiO}_3 \cdot \text{TiO}_2 \cdot \text{B}_2\text{O}_3$. Monoclinic. In basal plates. Perfect basal cleavage. $H = 5.5$, $G = 4.2$. $a = 0.01$, $b = 0.01$, $c = 0.01$. $2V = 77^\circ$. From the island of Årøy in the Lofoten group, north of Lofoten, Norway.

Jeromeite. From the Jerome mine, Idaho. $\text{Ca} \cdot \text{pyrophen} \cdot \text{Fe} \cdot \text{MgO} \cdot \text{B}_2\text{O}_3 \cdot \text{MnO} \cdot \text{MnO}_2$. Orthorhombic. In small fragments in white or cream-colored clay. $H = 6$, $G = 5.5$. Luster vitreous. For loose specimens. $Ax = 0.01$, $B = 0.01$, $C = 0.01$, $a = 0.01$, $b = 0.01$, $c = 0.01$. $2V = 34^\circ$. From Langlands Pass, Vermilion, Nevada.

Humbergite. $\text{Fe} \cdot \text{MgO} \cdot \text{B}_2\text{O}_3$. In gray to white orthorhombic prismatic crystals. X rays of the above are due to the at. wt. of Fe . Cleavage (01) perfect. $H = 6$, $G = 5.5$. $a = 0.01$, $b = 0.01$, $c = 0.01$. $2V = 77^\circ$. From the island of Årøy in the Lofoten group, north of Lofoten, Norway.

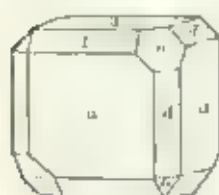
Strawberry. $2\text{Mg} \cdot \text{B}_2\text{O}_3 \cdot \text{MgO}$. A small greenish white crystal. $H = 6$, $G = 5.5$. Luster vitreous. For loose specimens. $Ax = 0.01$, $B = 0.01$, $C = 0.01$, $a = 0.01$, $b = 0.01$, $c = 0.01$. $2V = 34^\circ$. From Langlands Pass, Vermilion, Nevada.

Cambridge. $\text{MgO} \cdot \text{B}_2\text{O}_3 \cdot \text{MgO}$. A small greenish white crystal. $H = 6$, $G = 5.5$. Luster vitreous. For loose specimens. $Ax = 0.01$, $B = 0.01$, $C = 0.01$, $a = 0.01$, $b = 0.01$, $c = 0.01$. $2V = 34^\circ$. From Langlands Pass, Vermilion, Nevada.

BORACITE.

Isometric and tetrahedral in external form under ordinary conditions, but in molecular structure orthorhombic and pseudo-cubic, the latter becoming isotropic, as required by the form, only when heated to 265° . (See Art. 441.)

1030



1031



1032



Habit cubic and tetrahedral or octahedral, also dodecahedral. Crystals usually uniaxial, euhedral, less often in groups. Faces $\{111\}$ bright and sharp, $\{110\}$ dull or uneven.

Cleavage $\{111\}$, in angles. Fracture conchoidal uneven. Brittle. $H = 7$ in crystals. $G = 2.9$. Luster vitreous, becoming adamantine. Color white, inclining to gray, yellow and green. Streak white. Subtransparent.

to translucent. Commonly shows double refraction which, however, disappears upon heating to 245° with a reduction in birefringence. Optically $n_x = 1.565$, $n_y = 1.567$, n_z large.

Strongly pyroelectric. Opposite polarity corresponding to the position of the basal structural layers (see fig. 10.10). The faces of the $\{111\}$ tetrahedron, $\{011\}$, both the cleavage and pole faces of the pyroelectric form (1) the antilogous pair.

Comp. $\text{Mg}_2\text{Si}_2\text{O}_7$, Si_2O_7 or $5\text{MgO} \cdot 2\text{SiO}_2$.

Var. 1. *Orthorhombic*. Crystals of small habit. S. Monoclinic with monoclinic pyroelectricity. The $\{111\}$ faces are $\{110\}$ in the monoclinic form. The faces of the $\{111\}$ tetrahedron, $\{011\}$, both the cleavage and pole faces of the pyroelectric form (1) the antilogous pair.

Var. 2. *Monoclinic*. Crystals of small habit. S. Monoclinic with monoclinic pyroelectricity. The $\{111\}$ faces are $\{110\}$ in the monoclinic form. The faces of the $\{111\}$ tetrahedron, $\{011\}$, both the cleavage and pole faces of the pyroelectric form (1) the antilogous pair.

Var. 3. *Trigonal*. Crystals of small habit. S. Trigonal with trigonal pyroelectricity. The $\{111\}$ faces are $\{110\}$ in the trigonal form. The faces of the $\{111\}$ tetrahedron, $\{011\}$, both the cleavage and pole faces of the pyroelectric form (1) the antilogous pair.

Var. 4. *Trigonal*. Crystals of small habit. S. Trigonal with trigonal pyroelectricity. The $\{111\}$ faces are $\{110\}$ in the trigonal form. The faces of the $\{111\}$ tetrahedron, $\{011\}$, both the cleavage and pole faces of the pyroelectric form (1) the antilogous pair.

Var. 5. *Trigonal*. Crystals of small habit. S. Trigonal with trigonal pyroelectricity. The $\{111\}$ faces are $\{110\}$ in the trigonal form. The faces of the $\{111\}$ tetrahedron, $\{011\}$, both the cleavage and pole faces of the pyroelectric form (1) the antilogous pair.

Var. 6. *Trigonal*. Crystals of small habit. S. Trigonal with trigonal pyroelectricity. The $\{111\}$ faces are $\{110\}$ in the trigonal form. The faces of the $\{111\}$ tetrahedron, $\{011\}$, both the cleavage and pole faces of the pyroelectric form (1) the antilogous pair.

Var. 7. *Trigonal*. Crystals of small habit. S. Trigonal with trigonal pyroelectricity. The $\{111\}$ faces are $\{110\}$ in the trigonal form. The faces of the $\{111\}$ tetrahedron, $\{011\}$, both the cleavage and pole faces of the pyroelectric form (1) the antilogous pair.

Var. 8. *Trigonal*. Crystals of small habit. S. Trigonal with trigonal pyroelectricity. The $\{111\}$ faces are $\{110\}$ in the trigonal form. The faces of the $\{111\}$ tetrahedron, $\{011\}$, both the cleavage and pole faces of the pyroelectric form (1) the antilogous pair.

Var. 9. *Trigonal*. Crystals of small habit. S. Trigonal with trigonal pyroelectricity. The $\{111\}$ faces are $\{110\}$ in the trigonal form. The faces of the $\{111\}$ tetrahedron, $\{011\}$, both the cleavage and pole faces of the pyroelectric form (1) the antilogous pair.

Var. 10. *Trigonal*. Crystals of small habit. S. Trigonal with trigonal pyroelectricity. The $\{111\}$ faces are $\{110\}$ in the trigonal form. The faces of the $\{111\}$ tetrahedron, $\{011\}$, both the cleavage and pole faces of the pyroelectric form (1) the antilogous pair.

Var. 11. *Trigonal*. Crystals of small habit. S. Trigonal with trigonal pyroelectricity. The $\{111\}$ faces are $\{110\}$ in the trigonal form. The faces of the $\{111\}$ tetrahedron, $\{011\}$, both the cleavage and pole faces of the pyroelectric form (1) the antilogous pair.

Pyrr., etc. — H B. decolorizes, turns white, and fuses at 1.5 to a white enamel, coloring the flame intensely yellow. On charcoal fuses in C to a clear bead. In R F a part is absorbed by the charcoal, leaving an infusible opaque residue. Soluble in hydrochloric acid. In water it loses its granular aspect, is gradually dissolved, leaving a residue of calcium sulphate, and a large excess of water completely dissolves.

Obs. — The most important localities are: — Found in Salsburg, Austria, at Dorenberg near Innsbruck, at Ischl near Salzburg, and in the neighboring town of Reichenbach in Tyrol, Austria. In the Province of Saxony at Dornburg near Wittenberg and at Leisnig near Arthur near Stettin. In Spain at Vitoria near Gueiza in the Province of Vizcaya and at Gueiza near Leiz in the Province of Madrid. In India at the Mayo mine near Khowa, the Poonah mine near Chikmagalur near Mysore, and at the Poonah mine in the K. V. mine valley, Yavapai Co., Arizona. In California, from Borax Lake, San Bernardino Co.

Langbeinite. $\text{K}_2\text{Mg}_2\text{SO}_4$. Isometric-crystalloidal. In highly modified colorless crystals. $G = 2.84$, $n = 1.535$. From Wittenberg and Salsburg, Germany; Hall, Tyrol, Austria, India.

Masses, selenite. $\text{K}_2\text{Mg}_2\text{SO}_4$. A sulphate of magnesium and potassium, supposed to have been a decomposition product of a more complex character with the artificial mix of this composition. It is a colorless, transparent, tabular crystal, $G = 1.572$. It is soluble in water, and is a constituent of the mineral water at Vichy, France.

Vandenbergite. $\text{Na}_2\text{SO}_4 \cdot \text{MgSO}_4$. A more colorless crystalline mass, as found at Vandenberg, near Stassfurt, Prussia.

Barite Group. RSO_4 . Orthorhombic

| | | $m \wedge m''$
110 \wedge 110 | dd'
102 \wedge 102 | oo'
011 \wedge 011 | a | b | c |
|-----------|-----------------|------------------------------------|---------------------------|---------------------------|--------|-----|--------|
| Barite | BaSO_4 | 75° 22' | 77° 43' | 105° 26' | 0.8152 | 1 | 1.3136 |
| Celestine | SrSO_4 | 75° 50' | 78° 40' | 104° 20' | 0.7700 | 1 | 1.2801 |
| Anglesite | PbSO_4 | 76° 16' | 78° 47' | 104° 23' | 0.7852 | 1 | 1.2804 |

The Barite Group includes the sulphates of barium, strontium, and lead, three species which are closely isomorphous, agreeing not only in name but also in crystalline habit and cleavage.

A ray study of barite, celestine and anglesite shows that the optical characters agree with orthorhombic crystals, the dimensions of which correspond to that of the crystal axes in the ratio of 2a, 4b, 2c.

BARITE. Heavy Spar. Barytes.

Orthorhombic. Axes a b $c = 0.8152$ 1 1.3136

| | | | |
|----------------|----------------------------|---------------|----------------------------|
| α_{100} | 110 \wedge 110 = 75° 22' | dd' | 012 \wedge 105 = 132° 7' |
| α_{01} | 001 \wedge 01 = 39° 54' | α_{01} | 01 \wedge 011 = 71° 33' |
| α_{01} | 001 \wedge 011 = 52° 48' | α_{01} | 003 \wedge 111 = 61° 3' |

Crystals commonly tabular $\{001\}$ and rated in diverging groups having the axis b in common. Also prismatic, most frequently $\{110\}$ and $\{102\}$ predominating. Also $\{110\}$ prominent, again $\{110\}$ with $\{011\}$ prominent. Also globular forms fibrous or lamellar, crystalline, coarsely laminated, laminae convergent and often curved, granular, resembling white marble, and earthy. Colors sometimes banded as in stalagmites.

Cleavage $\{001\}$ perfect, $\{110\}$ also perfect. Fig. 103. The form yielded by cleavage, also $\{010\}$ imperfect. Fracture uneven. Br. 10. H = 2.5-2.5. $G = 4.3-4.6$. Luster vitreous, passing to resinous. Semitransparent to nearly opaque. Less often black or red. Streak white. Color white, also inclining to yellow, gray, blue, red, or brown, dark brown. Transparent to

Mimosaerzichte. Normal ferric and chromous sulphate. As a violet incrustation, Alamogordo, island of Yucatan, Yucatan Islands.

CROCOITE.

Monoclinic. Axes $a : b : c = 0.9043 : 1 : 0.9150$, $\beta = 77^\circ 33'$

1002

mm, $100 \wedge 110 = 96^\circ 10'$
 cr, $100 \wedge 111 = 49^\circ 32'$

$a, 111 \wedge 111 = 60^\circ 50'$
 cr, $101 \wedge 11 = 46^\circ 58'$



Crystals usually prismatic, habit varied. Also imperfectly columnar and granular.

Fracture *conchoidal*, rather distinct, c (001), a (100), less so. Fracture small conchoidal to uneven. Sects $\parallel H = 2.5-3$ (1) $\times 0.0-0.1$. Luster of fracture to vitreous. Color various shades of bright hyacinthine. Streak orange-yellow. Translucent to slightly \times . Ax. pr. (001) $Z \wedge c$ axis $= -5^\circ$, $a = 2.1$, $\beta = 37^\circ$, $\gamma = 2.66$, $2V = 57^\circ$.

Comp. Lead chromate, $PbCrO_4 =$ Chromium trioxide 31.1, lead protoxide 68.9 = 100.

Py., etc. In the moist state decomposes, blackens, but loses very perceptible color on heating. Red fumes of CrO_3 are given off as residue. On heating with the agent c and with a rod of iron c is c to c at c giving a small coating. With salt of phosphorus gives an orange-red color with c with c .

Obs. A variety of crocoite is found deposited from hot solutions containing chromium, that has been found in the mountains of lead and silver in the Lead Mountains, Missouri, at Leadville, and elsewhere. From the Lead Mountains, Missouri, it is found in a form crystalline from the Hot Springs River. From Leadville, Missouri, it is found in a form crystalline from the Hot Springs River. From Leadville, Missouri, it is found in a form crystalline from the Hot Springs River. From Leadville, Missouri, it is found in a form crystalline from the Hot Springs River.

See also *Lead and Silver*, *Lead*.

Phosphocrocoite. $PbCrO_4$ and chromate, $PbCrO_4$ and CrO_3 , in orthorhombic crystals with c and c perfect cleavage. $H = 3$, $c = 2.5$, $2V = 57^\circ$. Good in Leadville, Missouri, and in the mountains of lead and silver in the Lead Mountains, Missouri. Strongly hygroscopic. Fracture uneven, at right angles to c and c .

Vauquelinite. A lead chromate of the formula $PbCrO_4$, $c = 2.5$, $2V = 57^\circ$. It is found in the mountains of lead and silver in the Lead Mountains, Missouri, and in the mountains of lead and silver in the Lead Mountains, Missouri. It is found in the mountains of lead and silver in the Lead Mountains, Missouri, and in the mountains of lead and silver in the Lead Mountains, Missouri. It is found in the mountains of lead and silver in the Lead Mountains, Missouri, and in the mountains of lead and silver in the Lead Mountains, Missouri.

See *Lead and Silver*, *Lead*.

Beilite. Lead chromate in which c is replaced by c . It is found in the mountains of lead and silver in the Lead Mountains, Missouri, and in the mountains of lead and silver in the Lead Mountains, Missouri. It is found in the mountains of lead and silver in the Lead Mountains, Missouri, and in the mountains of lead and silver in the Lead Mountains, Missouri.

Thapsacite. $PbCrO_4$, $c = 2.5$, $2V = 57^\circ$. It is found in the mountains of lead and silver in the Lead Mountains, Missouri, and in the mountains of lead and silver in the Lead Mountains, Missouri. It is found in the mountains of lead and silver in the Lead Mountains, Missouri, and in the mountains of lead and silver in the Lead Mountains, Missouri.

Sulphates with Chlorides, Carbonates, etc. In part hydrous

LEADBILITE

Monoclinic. Axes $a : b : c = 1.7476 : 1 : 2.2154$, $\beta = 80^\circ 48'$

mm, $110 \wedge 110 = 120^\circ 27'$
 cr, $001 \wedge 101 = 61^\circ 36'$

cr, $101 \wedge 11 = 88^\circ 31'$
 cr, $001 \wedge 110 = 89^\circ 54'$

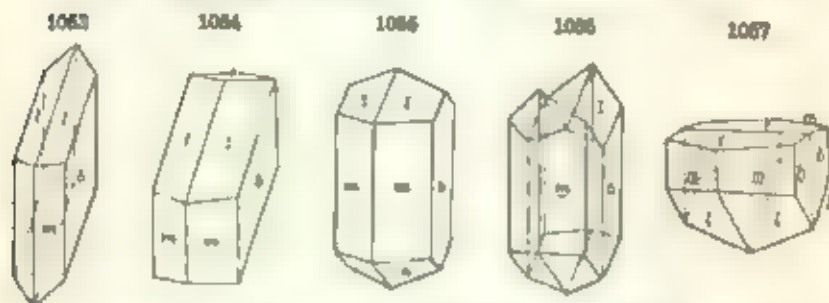
Twins (tw pl m 1101, analogous to aragonite). Crystals commonly tabular $\parallel c(001)$.

Smekite. $\text{MnSO}_4 \cdot \text{B}_2\text{O}_3$ Probably monoclinic. One cleavage. Stalactitic. $H = 1.5$. $G = 3.16$. Whitish, reddish. Indices, 1.57-1.62. From Felsőhány, (Bala Sprie, Romania).

GYPSUM

Monoclinic. Axes $a : b : c = 0.6899 : 1 : 0.4124$, $\beta = 80^\circ 42'$.

| | | | |
|------------|---------------------------------------|-------|---------------------------------------|
| $m\bar{m}$ | $110 \wedge 1\bar{1}0 = 68^\circ 30'$ | h' | $111 \wedge 1\bar{1}1 = 36^\circ 12'$ |
| cd | $001 \wedge 101 = 28^\circ 17'$ | mn' | $111 \wedge 1\bar{1}1 = 41^\circ 20'$ |
| cd | $001 \wedge 101 = 33^\circ 04'$ | md | $110 \wedge 111 = 49^\circ 19'$ |
| cd | $001 \wedge 101 = 11^\circ 29'$ | $m'a$ | $110 \wedge 111 = 59^\circ 15'$ |
| mv' | $011 \wedge 0\bar{1}1 = 44^\circ 17'$ | | |



Crystals usually simple in habit, common form flattened $\parallel b(010)$ or prismatic to acicular c axis, again prismatic by extension of $a(111)$. Also lenticular by rounding of $h(111)$ and $a(113)$. The form $a(113)$, whose faces are usually rough or convex, is nearly at right angles to the vertical axis (edge $m(110) m'(110)$), hence the apparent hemi-spherical character of the twin (Fig. 1057). Some crystals often with warped as well as curved surfaces. Also foliated massive, lamellar stearate, often granular massive, and sometimes nearly unrecognizable. Twins tw. pl. $a(100)$ very common, often the familiar swallow-tail twins. X-ray study of the crystal structure shows eight molecules in the unit cell. Each calcium atom is between six complex atomic groups, consisting of four SO_4 tetrahedrons and two molecules of water.



Cleavage $b(010)$ eminent, yielding easily than polished folia $a(100)$, giving a surface with conchoidal fracture $a(111)$, with a fibrous fracture $c(001)$; a cleavage fragment has the rhombic form of Fig. 1058, with plane angles of 90° and 114° . $H = 1.5-2$. $G = 2.314-2.328$, when in pure crystals. Luster of $b(010)$ pearly and shining, other faces subvitreous. Massive varieties often glassy, sometimes dull earthy. Color usually white, sometimes gray, flesh-red, honey yellow, ochre-yellow, blue; impure varieties often black, brown, red, or reddish brown. Struck white. Transparent to opaque.

Optically +. Ax. pl. $\parallel b(010)$ and $Z \setminus c$ axis $= +52.1^\circ$ (at 9.4°C) (cf. Fig. 1058). Dispersion $\sigma > \nu$, also $\mu_{\text{max}} - \mu_{\text{min}} = 0.002$. $2V = 58^\circ$. $\alpha = 1.520$. $\beta = 1.521$. $\gamma = 1.530$. The optic axial angle increases rapidly with rise of temperature, becoming 0° for the D line at 91°C , see further on p. 325.

Var. 1. Crystals of a hexagonal or rhombic form, sometimes in flat, four-sided or hexagonal prisms, sometimes in thin, flat, hexagonal plates. The crystals are colorless, transparent, and have a vitreous luster. They are rather brittle.

2. Crystals of a hexagonal or rhombic form, sometimes in flat, four-sided or hexagonal prisms, sometimes in thin, flat, hexagonal plates. The crystals are colorless, transparent, and have a vitreous luster. They are rather brittle.

3. Crystals of a hexagonal or rhombic form, sometimes in flat, four-sided or hexagonal prisms, sometimes in thin, flat, hexagonal plates. The crystals are colorless, transparent, and have a vitreous luster. They are rather brittle.

Comp. Hydrous calcium sulphate, $(\text{CaSO}_4)_2 \cdot 2\text{H}_2\text{O}$ = Sulphur trioxide 46 lb. and 32 1/2 water 200 = 100

Pre. etc. - In the cement group of water and lime, the cement is formed at 2 1/2% of the weight of the cement. The cement is formed at 2 1/2% of the weight of the cement. The cement is formed at 2 1/2% of the weight of the cement.

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Bianchira. — $\text{FeSO}_4 \cdot \text{ZnSO}_4 \cdot 12\text{H}_2\text{O}$. Crystals monoclinal. Crystalline crust. White. Occurs in the form of a white crust on the walls of a mine at Bianchira, near Prato, Venetia, Italy. (Forst.) Canada.

Epsomite Group. $\text{R}_2\text{SO}_4 \cdot 7\text{H}_2\text{O}$ Orthorhombic

| | | |
|------------|----------------------------------------------------|-----------------------------------|
| Epsomite | $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$ | $a : b : c = 0.9902 : 1 : 0.9790$ |
| Gislarite | $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ | $0.9807 : 1 : 0.9641$ |
| Morenosite | $\text{Na}_2\text{SO}_4 \cdot 7\text{H}_2\text{O}$ | $0.9816 : 1 : 0.9645$ |

EPSOMITE. Epsom Salt.

Crystals cubic. Sphenoidal. See Fig. 344, p. 345. Usually in heavy white masses and frequently fulfils cracks. Cleavage {110} very perfect, {011} less so. Fracture conchoidal. $H = 2.0$; $G = 1.751$. Lighter varieties owe to purity. Struck and color white. Transparent to translucent. Taste bitter and saline. Usually. $\text{Xr pl} = 001$. $\lambda = b \text{ axis}$. $2V = 52^\circ$. $n = 1.433$, $\beta = 1.455$, $\gamma = 1.461$.

Comp. — It is in its anhydrous state, $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$. Soluble in water. It is a common salt in the water of the Dead Sea. It is a common salt in the water of the Dead Sea.

Obs. — It is found in several waters. It is a common salt in the water of the Dead Sea. It is a common salt in the water of the Dead Sea. It is a common salt in the water of the Dead Sea.

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Melanterite Group. $RSO_4 \cdot 7H_2O$ Monoclinic

| | | $a:b:c$ | β |
|----------------|----------------------------|---------------------|------------------------|
| Melanterite | $FeSO_4 \cdot 7H_2O$ | 1.1828 : 1 : 1.5427 | $\beta = 75^\circ 44'$ |
| Mallardite | $MnSO_4 \cdot 7H_2O$ | | |
| Pisanite | $Fe_2(CuSO_4 \cdot 7H_2O)$ | 1.1609 : 1 : 1.5110 | $74^\circ 38'$ |
| Bieberite | $CuSO_4 \cdot 7H_2O$ | 1.1815 : 1 : 1.5325 | $75^\circ 20'$ |
| Capromagnesite | $(Ca, Mg)SO_4 \cdot 7H_2O$ | | |
| Boothite | $CuSO_4 \cdot 7H_2O$ | 1.1622 : 1 : 1.5000 | $74^\circ 24'$ |

The species here included are the ordinary varieties. They are identical in general formula with the species of the Pisanite group, and are regarded as essentially the same compounds under oblique crystallization.

MELANTERITE. Copperas.

Monoclinic. Usually capillary, fibrous, acicular, and subcrystalline, also massive, pulverulent. Cleavage (100) perfect in 110, less so in 100. Rare conchoidal. Brittle. $H = 2$. $d = 1.80-1.90$. Fairly soluble. Astringent taste. Luster yellowish. Color various shades of green, passing into white, becoming yellow in exposure. Streak iron-red. Soluble, parent to trisulphate. Taste sweetish, as in green, and metallic. Optically. Ax. pl. (010). Z A c axis = 61° . $\alpha = 1.471$, $\beta = 1.478$, $\gamma = 1.486$. $2V = 69^\circ$.

Comp. — Hydrated ferric sulphate. $FeSO_4 \cdot 7H_2O =$ sulphur trioxide 28.8, iron peroxide 25.0, water 45.3 = 100. Magnesium and manganese sometimes replace part of the iron.

Obs. — Occurs in various localities from the decomposition of pyrite or marcasite which readily effloresce. It was first discovered when a sample of pyrite from the mines of the Harz Mountains was found to contain a small quantity of a white crystalline substance. This substance was found to be a new mineral, and was named after the Harz Mountains. It is a common mineral in the Harz Mountains, and is also found in the Harz Mountains. It is a common mineral in the Harz Mountains, and is also found in the Harz Mountains.

Mallardite — $MnSO_4 \cdot 7H_2O$. Ferric massive, colorless. From Lake Bay in the Harz Mountains. $H = 2$. $d = 1.80$.

Pisanite — $(Fe, Cu)SO_4 \cdot 7H_2O$. $CuSO_4$ 10 to 18 per cent. Massive. In some specimens and in some localities. $H = 2$. $d = 1.80$. Optically. Ax. pl. (010). Z A c axis = 61° . $\alpha = 1.471$, $\beta = 1.478$, $\gamma = 1.486$. $2V = 69^\circ$. Formed by the decomposition of pyrite or marcasite. It is a common mineral in the Harz Mountains, and is also found in the Harz Mountains. It is a common mineral in the Harz Mountains, and is also found in the Harz Mountains.

Boothite — $CuSO_4 \cdot 7H_2O$. Ferric massive, colorless. From Lake Bay in the Harz Mountains. $H = 2$. $d = 1.80$. Optically. Ax. pl. (010). Z A c axis = 61° . $\alpha = 1.471$, $\beta = 1.478$, $\gamma = 1.486$. $2V = 69^\circ$. Formed by the decomposition of pyrite or marcasite. It is a common mineral in the Harz Mountains, and is also found in the Harz Mountains.

Bieberite — $CuSO_4 \cdot 7H_2O$. Ferric massive, colorless. From Lake Bay in the Harz Mountains. $H = 2$. $d = 1.80$. Optically. Ax. pl. (010). Z A c axis = 61° . $\alpha = 1.471$, $\beta = 1.478$, $\gamma = 1.486$. $2V = 69^\circ$. Formed by the decomposition of pyrite or marcasite. It is a common mineral in the Harz Mountains, and is also found in the Harz Mountains.

Capromagnesite — $(Ca, Mg)SO_4 \cdot 7H_2O$. Ferric massive, colorless. From Lake Bay in the Harz Mountains. $H = 2$. $d = 1.80$. Optically. Ax. pl. (010). Z A c axis = 61° . $\alpha = 1.471$, $\beta = 1.478$, $\gamma = 1.486$. $2V = 69^\circ$. Formed by the decomposition of pyrite or marcasite. It is a common mineral in the Harz Mountains, and is also found in the Harz Mountains.

$\gamma = 1.494$, $2V = 71^\circ$ Strong dispersion, $p < v$. From the salt deposit at Hallstadt (Germany), Salzburg. Also at Munsdorf, Province of Saxony and at Leopoldsdall in Austria. From the salt lakes of Austrian provinces of Tyrol and Carinthia, in Punjab, India. In Antofagasta, Chile at Iquique and Chuquibambilla. In New Mexico at Salt Lake, near Espanola, Ventura Co. and at Soda Lake, San Bernardino Co.

Leucite $MgSi_2O_6 \cdot 4H_2O$ Monoclinic. $H = 3$, $C = 1.25$ easily fusible. Colorless. Optically - $Ax \parallel C$, Z nearly $AXIS$, $\alpha = 1.483$, $\beta = 1.487$, $\gamma = 1.486$, $2V = 90^\circ$. From the salt deposits of Werraingen, Province of Saxony and of Leopoldsdall, Austria.

Boussingaultite $NH_4SO_4 \cdot MgSO_4 \cdot 6H_2O$ Monoclinic. Cleavage, 201° perfect. $H = 2$, $C = 1.7$. Very easily fusible. Optically - $Ax \parallel C$, $Z \perp C$, $\alpha = 1.4$, $\beta = 1.47$, $\gamma = 1.472$, $2V = 142^\circ$, $2V' = 51^\circ$. From the lake and springs, Germany, Italy. Also on South Mountain near Santa Paula, Ventura Co., California.

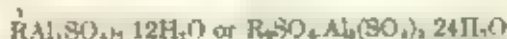
Picromerite $MgSO_4 \cdot K_2SO_4 \cdot 6H_2O$ As a white crystalline crustation. Monoclinic. Cleavage, 201° perfect. $H = 2.5$, $C = 2.1$ easily fusible. Optically - $Ax \parallel C$, $Z \perp C$, $\alpha = 1.4$, $\beta = 1.46$, $\gamma = 1.46$, $2V = 147^\circ$, $2V' = 48^\circ$. From Venice as well as picromerite an isomorphous species in which copper replaces the magnesium. Also at Munsdorf, Austria and Leopoldsdall, Province of Saxony, at Leopoldsdall in Austria. From Hungary and in Poland.

Polyhaute $2H_2O \cdot MgSO_4 \cdot K_2SO_4$ Triclinic. Usually in radiating fibrous or lamellar masses. Cleavage, 100° distinct. $H = 2.5$, $C = 2.7$ easily fusible. Optically - $Ax \parallel C$, $Z \perp C$, $\alpha = 1.46$, $\beta = 1.462$, $\gamma = 1.462$, $2V = 110^\circ$. From the mines of Hallstadt, etc. in Salzburg, Austria. In Germany at Berchtesgaden, Bavaria. Also at the mine of Hallstadt, etc. in Salzburg, Austria.

Heulandite $MgSi_2O_6 \cdot 4H_2O$ Monoclinic. Common to fibrous structure. Cleavage, 100° distinct. $H = 1.7$ soft, white with a light green tinge. Easily water soluble. Optically - $Ax \parallel C$, $Z \perp C$, $\alpha = 1.453$, $\beta = 1.453$, $\gamma = 1.453$, $2V = 145^\circ$, $2V' = 145^\circ$. From the mines of Hallstadt, etc. in Salzburg, Austria.

Mooserite $R_2Si_2O_6 \cdot 4H_2O$, $R = Mg, Mn, Zn$, 4 , $1, 2$ Monoclinic. Crystals in clear prisms. Cleavage, 100° , perfect. $C = 2.4$, $H = 3$. Color clear, slightly white. Optically - $Ax \parallel C$, $Z \perp C$, $\alpha = 1.45$, $\beta = 1.45$, $\gamma = 1.45$, $2V = 144^\circ$. Occurs with altered pyroxene, rhodochrosite and quartz at Franklin, Sussex Co., New Jersey. Also at the mine of Hallstadt, etc. in Salzburg, Austria. In Germany at Berchtesgaden, Bavaria. Also at the mine of Hallstadt, etc. in Salzburg, Austria. In New Jersey at Franklin, Sussex Co. with the same associated. Black when in color. Comp. $H_2Si_2O_6 \cdot 6R_2O \cdot 4H_2O$ with $R = Mg, Mn, Zn = 5, 3, 4$. $\alpha = 1.570$, $\beta = 1.584$, $\gamma = 1.585$.

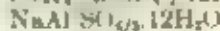
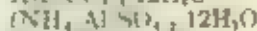
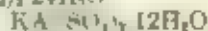
Alum Group. Isometric



Potash Alum

Ammonia Alum, Tschermakite

Soda Alum



The Alums proper are isometric in crystallization and, chemically, are hydrous sulphates of aluminum with an alkali metal and 12, i.e., if the formula is doubled, 24) molecules of water. The species listed above occur very sparingly in nature, and are best known in artificial form in the laboratory.

Potash Alum $KAl_2(SO_4)_3 \cdot 12H_2O$ Isometric. Detached habit. $H = 2$, $C = 1.7$. Very easily fusible. Optically - $Ax \parallel C$, $Z \perp C$, $\alpha = 1.43$. Also isometric, with the same composition. Probably monoclinic. Fibrous. Optically - $Ax \parallel C$, $Z \perp C$, $\alpha = 1.43$, $\beta = 1.43$, $\gamma = 1.43$, $2V = 145^\circ$. These minerals are often formed by the weathering of aluminous rocks, sometimes, which contain pyrite and bituminous material, and they may occur in large amounts in such formations. The action of ascending waters containing sulphuric acid which has been derived from either some volcanic source or through the oxidation of sulphides, upon rocks containing potassium and sodium silicates will also form them. They occur frequently as an efflorescence upon stratioid minerals. Found in connection with volcanic rocks, etc. as on the island of Vulcano, Lipari Islands, at Vesuvius, at the solfatare at Cape Miseno, etc., near Naples.

(Cleavage: $c(001)$ $H = 2.5$, $G = 2.103$ Luster pearly Color sulphate-yellow, straw-yellow Translucent Optically + Ax pl (010) $X = c$ axis. $\alpha = 1.500-1.540$, $\beta = 1.528-1.550$, $\gamma = 1.575-1.600$ $2V = 45^\circ$ to 74°

Comp. - A basic ferric sulphate, perhaps $Fe_2(OH)_2SO_4 \cdot 14H_2O$

It is an old term, which has been somewhat vaguely applied. It seems to belong to part here and to part elsewhere, but is not a mineral with definite composition.

Pyr., etc. - It is water and a residue, which is a mixture of iron and sulphur. It is a mixture of iron and sulphur, and is a mixture of iron and sulphur. It is a mixture of iron and sulphur, and is a mixture of iron and sulphur.

Obs. - The mineral is a mixture of iron and sulphur. It is a mixture of iron and sulphur, and is a mixture of iron and sulphur. It is a mixture of iron and sulphur, and is a mixture of iron and sulphur. It is a mixture of iron and sulphur, and is a mixture of iron and sulphur.

The mineral is a mixture of iron and sulphur. It is a mixture of iron and sulphur, and is a mixture of iron and sulphur. It is a mixture of iron and sulphur, and is a mixture of iron and sulphur. It is a mixture of iron and sulphur, and is a mixture of iron and sulphur.

Other hydrated ferric sulphates

Rhombohedral - A hydrated acid ferric sulphate $Fe_2O_3 \cdot 4SO_3 \cdot 11H_2O$ Orthorhombic or monoclinic. Color brownish-yellow. It is a mixture of iron and sulphur. It is a mixture of iron and sulphur, and is a mixture of iron and sulphur.

Trigonal prismatic - A hydrated acid ferric sulphate $Fe_2O_3 \cdot 4SO_3 \cdot 11H_2O$ Trigonal prismatic. Color brownish-yellow. It is a mixture of iron and sulphur. It is a mixture of iron and sulphur, and is a mixture of iron and sulphur.

Trigonal prismatic - A hydrated acid ferric sulphate $Fe_2O_3 \cdot 4SO_3 \cdot 11H_2O$ Trigonal prismatic. Color brownish-yellow. It is a mixture of iron and sulphur. It is a mixture of iron and sulphur, and is a mixture of iron and sulphur.

Trigonal prismatic - A hydrated acid ferric sulphate $Fe_2O_3 \cdot 4SO_3 \cdot 11H_2O$ Trigonal prismatic. Color brownish-yellow. It is a mixture of iron and sulphur. It is a mixture of iron and sulphur, and is a mixture of iron and sulphur.

Bullerite - $Fe_2O_3 \cdot 2SO_3 \cdot 7H_2O$ Orthorhombic. In minute prismatic crystals. Color grey. It is a mixture of iron and sulphur. It is a mixture of iron and sulphur, and is a mixture of iron and sulphur.

Amazonsite - $Fe_2O_3 \cdot 2SO_3 \cdot 7H_2O$ Trigonal prismatic. In columnar or fibrous masses. Color straw-yellow. It is a mixture of iron and sulphur. It is a mixture of iron and sulphur, and is a mixture of iron and sulphur.

Picroferrite - $Fe_2O_3 \cdot 2SO_3 \cdot 7H_2O$ Orthorhombic. In deceptively fibrous aggregates. $H = 2.5$, $G = 1.9$ Elastic. Color pale yellow, nearly white. Optically - Z elongation of fibers. In some varieties $\alpha = 1.550-1.560$. From Ecuador, Calif., France, and from the Sierra Nevada near Coquima, Atacama, Chile.

Rauvoharite - $2Fe_2O_3 \cdot 2SO_3 \cdot 7H_2O$ In thin, wavy plates. Color between honey- and ochre-yellow. It is a mixture of iron and sulphur. It is a mixture of iron and sulphur, and is a mixture of iron and sulphur.

Greenish earth - $3Fe_2O_3 \cdot 4SO_3 \cdot 7H_2O$ In soft, waxy masses, and in crustations also in micaceous lamellae. $H = 4$, $G = 2.6$ Color straw-yellow. It is a mixture of iron and sulphur. It is a mixture of iron and sulphur, and is a mixture of iron and sulphur.

ter somewhat nearly on base, otherwise vitreous. Optically negative. $\omega = 1.712$. Found in the same localities as Vesuvian.

Aluminate. $\text{Na}_2\text{SO}_4 \cdot \text{Al}_2\text{SO}_4 \cdot 4\text{H}_2\text{O}$. Compact. White. From Alameda, Spain.

Etringite. Perhaps $\text{Ca}(\text{Al}_2\text{Si}_2\text{O}_{10}) \cdot 3\text{H}_2\text{O}$. Hexagonal. In minute colorless acicular crystals. Diagnostic cleavage. $H = 2.5$. $G = 1.5$. Optically $\omega = 1.6$. From the same localities as lava, at Eitringen and Mayen in Rhineland. From Tomba, Italy.

Zincaluminite. $\text{Zn}(\text{Al}_2\text{Si}_2\text{O}_{10}) \cdot 6\text{H}_2\text{O}$. In minute hexagonal plates. $H = 2.5$. $G = 2.20$. Color white. Lustrous. $\omega = 1.54$, $\gamma = 1.544$. From Laurium, Greece.

Chalcocyanite. $\text{Zn}(\text{Al}_2\text{Si}_2\text{O}_{10}) \cdot 3\text{H}_2\text{O}$. Radiating fibrous. $G = 2.75$. $H = 1$. Blue. But it was shown by experiment that it is not a cyanite. From Laurium, Greece. No color in the cyanite test.

Chalcocyanite. $\text{Zn}(\text{Al}_2\text{Si}_2\text{O}_{10}) \cdot 3\text{H}_2\text{O}$. Radiating fibrous. In small colorless crystals. It was shown by experiment that it is not a cyanite. From Laurium, Greece. No color in the cyanite test. Several cleavages. $H = 2.5$. $G = 2.20$. $\omega = 1.54$, $\gamma = 1.544$. From Laurium, Greece. Optically $\omega = 1.54$, $\gamma = 1.544$. $2V = 30^\circ$. Strong dispersion, $\rho > \sigma$. Found at Daboe, γ = base Co., Arizona, with hematite and copper carbonate.

Johannite. $\text{Fe}(\text{Al}_2\text{Si}_2\text{O}_{10}) \cdot 3\text{H}_2\text{O}$. Triclinic. In druses or radiating aggregates or in minute tabular plates. No color in the cyanite test. Twinning in two directions. $H = 2$. $G = 1.5$. $\omega = 1.54$, $\gamma = 1.544$. Color greenish yellow to ochraceous. Optically $\omega = 1.54$, $\gamma = 1.544$. $2V = 30^\circ$. Found at Johann, Bolivia, and in the same locality, Bolivia, and in the same locality, Bolivia, and in the same locality, Bolivia.

Johannite. $\text{Fe}(\text{Al}_2\text{Si}_2\text{O}_{10}) \cdot 3\text{H}_2\text{O}$. Triclinic. In druses or radiating aggregates or in minute tabular plates. No color in the cyanite test. Twinning in two directions. $H = 2$. $G = 1.5$. $\omega = 1.54$, $\gamma = 1.544$. Color greenish yellow to ochraceous. Optically $\omega = 1.54$, $\gamma = 1.544$. $2V = 30^\circ$. Found at Johann, Bolivia, and in the same locality, Bolivia, and in the same locality, Bolivia.

Zippelite. $\text{Zn}(\text{Al}_2\text{Si}_2\text{O}_{10}) \cdot 3\text{H}_2\text{O}$. In small colorless crystals with hematite. $H = 2.5$. $G = 2.20$. $\omega = 1.54$, $\gamma = 1.544$. $2V = 30^\circ$. Found at Zippel, Bolivia, and in the same locality, Bolivia, and in the same locality, Bolivia.

Mineragrite. An anhydrous compound of white $\text{Ca}(\text{Al}_2\text{Si}_2\text{O}_{10}) \cdot 3\text{H}_2\text{O}$. Probably monoclinic. In granular aggregates. No color in the cyanite test. $H = 2.5$. $G = 1.5$. $\omega = 1.54$, $\gamma = 1.544$. Color blue. Optically $\omega = 1.54$, $\gamma = 1.544$. $2V = 30^\circ$. Found at Miner, Bolivia, and in the same locality, Bolivia, and in the same locality, Bolivia.

Mineragrite. An anhydrous compound of white $\text{Ca}(\text{Al}_2\text{Si}_2\text{O}_{10}) \cdot 3\text{H}_2\text{O}$. Probably monoclinic. In granular aggregates. No color in the cyanite test. $H = 2.5$. $G = 1.5$. $\omega = 1.54$, $\gamma = 1.544$. Color blue. Optically $\omega = 1.54$, $\gamma = 1.544$. $2V = 30^\circ$. Found at Miner, Bolivia, and in the same locality, Bolivia, and in the same locality, Bolivia.

Tellurates; also Tellurites, Selenites

Montanite. $\text{BiO}_3 \cdot \text{TeO}_3 \cdot 2\text{H}_2\text{O}$. Monoclinic? In rare, colorless, acicular to prismatic crystals. $H = 2.5$. $G = 1.5$. $\omega = 1.54$, $\gamma = 1.544$. Colorless. Optically $\omega = 1.54$, $\gamma = 1.544$. $2V = 30^\circ$. Found at Montan, New South Wales.

Euphrasite. $\text{Fe}(\text{Al}_2\text{Si}_2\text{O}_{10}) \cdot 3\text{H}_2\text{O}$. In thin green needles. $H = 2.5$. $G = 2.20$. $\omega = 1.54$, $\gamma = 1.544$. $2V = 30^\circ$. Strong dispersion, $\rho > \sigma$. $\omega = 1.54$, $\gamma = 1.544$. Found at Euphras, Arizona.

Purdumite. $\text{Fe}(\text{Al}_2\text{Si}_2\text{O}_{10}) \cdot 3\text{H}_2\text{O}$. Orthorhombic. In small prismatic crystals. $H = 2.5$. $G = 2.20$. $\omega = 1.54$, $\gamma = 1.544$. $2V = 30^\circ$. Strong dispersion, $\rho > \sigma$. Found at Purdum, California. Noted in the same locality, California.

Chalcocite.— $\text{Cu}_2\text{SeO}_3 \cdot 2\text{H}_2\text{O}$. In small blue monoclinic crystals. $H = 2.5-3$, $G = 3.70$. Easily fusible. Optically—Ax in 0 for red to green light, $\alpha = 1.710$, $\beta = 1.731$, $\gamma = 1.742$, $2V = 0^\circ$ for green light. From the Cerro de Cerchita, near Mendoza, Argentina, with silver-copper selenides. Also reported from Sierra de Linares and Sierra Famatina, La Rioja, Argentina.

Molybdenite is found separately and **Chalcocite** probably occurs minute, from the same locality as chalcocite.

Oxygen Salts

7. TUNGSTATES, MOLYBDATES

The monoclinic Wolframite Group and the tetragonal Scheelite Group are included here.

Wolframite Group

| | | | | | |
|------------|-----------------------------|-----------------------------------|------------------------|--|--|
| Ferberite | FeWO_4 | | | | |
| Wolframite | $(\text{Fe-Mn})\text{WO}_4$ | $a \ b \ c = 0.8255 \ 1 : 0.8094$ | $\beta = 89^\circ 32'$ | | |
| Hübnerite | MnWO_4 | | | | |
| Raspite | PbWO_4 | | | | |

WOLFRAMITE.

Monoclinic. See above for axes.

Twins. (1) tw axis c with $a(100)$ as comp.-face (2) tw pl $k(023)$ Fig. 475, p. 103. Crystals commonly tabular $a(100)$ also prismatic. Faces in prismatic zone vertically striated. Often bladed lamellar, coarse divergent columnar, granular.

Cleavage $b(110)$ very perfect also parting $a(100)$, and $c(102)$. **Fracture** uneven. **Brittle**. $H = 5.5-5$, $G = 7.7-5$. **Luster** submetallic. **Color** dark grayish or brownish black. **Streak** nearly black. **Opaque**. **Dioptase** weakly magnetic. **Optically** +. Ax in ± 010 , $Z \wedge c$ axis = $+17^\circ$ to 21° . $\beta = 24$, for ferberite, 23.2 for wolframite, 2.22 for hübnerite.

Comp.—Tungstate of iron and manganese $(\text{Fe,Mn})\text{WO}_4$.

Forms a series from ferberite FeWO_4 to hübnerite MnWO_4 . It has been suggested that ferberite should include that portion of the series containing up to 20 per cent MnWO_4 , hübnerite the portion containing up to 20 per cent FeWO_4 , and wolframite the remainder.

Pyrs. etc. Fuses 8 B easily. $F = 2-4$ to a glass, which has a crystalline surface and is magnetic. The fusing point rises with increase in percentage of the heavier molybdenes. With salt of phosphorus gives a clear reddish yellow glass when hot which is puer on cooling, in R.F. becomes dark red on charcoal, with an if not too antimony the bead remains on cooling a green color which continues treatment in R.F. changes to reddish yellow. With soda and water on pyrogram on 1 wire to a faint green fluorescence. Decomposed by aqua regia with separation of tungstic acid as a white powder. Sufficiently decomposed by concentrated nitric acid, or even hydrofluoric acid, to give a colorless solution, which, treated with metallic zinc, becomes transiently blue, but soon fades on dilution.

Obs. Wolframite is commonly found in granite and pegmatite veins having been formed under pneumatolytic conditions. It is very commonly associated with cassiterite but occurs at times in veins that are free from lead minerals. It is also sometimes in veins with stapherite minerals that have been formed under conditions of low heat and pressure. Often a constituent of placer deposits.

Some of the more important localities for its occurrence are as follows: From the Vindhya Chilian Mts., south of Nerchinsk in Transbaikalia, in Bohemia of Czechoslovakia at Schleg-



Ferrungastite. $\text{FeO}, \text{WO}_3, 6\text{H}_2\text{O}$. In microscopic hexagonal plates. Color pale yellow to brownish yellow. Decomposed by acids leaving yellow tungstic acid. Usually $\text{Fe} = 40, \text{W} = 172$. Product of oxidation of wolframite from Germania Tungsten mine, Deer Trail district, Washington.

VII. SALTS OF ORGANIC ACIDS

Oxalates, Malates

Whewellite.—Calcium oxalate, $\text{CaC}_2\text{O}_4 \cdot \text{H}_2\text{O}$. In small colorless rhombohedral crystals. Several cleavages. $\text{H} = 1.5$, $\text{G} = 2.25$. Optically +. Ax. pl. 1 (010). $2\text{A axis} = 20^\circ$, $\alpha = 1.60$, $n = 1.555$, $\gamma = 1.650$. Commonly occurs with carbonaceous materials. In Saxony associated with mal at Heng near Chemnitz, and at Zwickau. Also found in an elsewhere in Bohemia of Czechoslovakia. In Arizona at the mouth of San Carlos river at Chino.

Oxalurate. Ammonium oxalate, $\text{NH}_4\text{C}_2\text{O}_4 \cdot 2\text{H}_2\text{O}$. Orthorhombic. Soft. $\text{G} = 1.48$. From Saline Wells. Optically. Ax. pl. 100. $\text{A} = 20^\circ$, $\alpha = 1.49$, $n = 1.54$, $\gamma = 1.565$. $2\text{V} = 62^\circ$. From the gang of the Saline Lake, Pers.

Hornblende. Hydrous ferrous oxalate, $\text{FeC}_2\text{O}_4 \cdot 2\text{H}_2\text{O}$. Orthorhombic. Optically. Ax. pl. 100. $\text{A} = 20^\circ$, $\alpha = 1.49$, $n = 1.54$, $\gamma = 1.565$. $2\text{V} = 62^\circ$. From the gang of the Saline Lake, Pers.

Malate. $\text{H} = 1.5$, $\text{G} = 2.25$. $\text{A} = 20^\circ$, $\alpha = 1.60$, $n = 1.555$, $\gamma = 1.650$. From the gang of the Saline Lake, Pers.

VIII. HYDROCARBON COMPOUNDS

The hydrocarbon compounds in general with few exceptions are not homogeneous substances, but mixtures, which by the use of modern analytical methods can be separated into a number of hydrocarbon compounds. They are here presented in a summary as a guide to the study of the hydrocarbon compounds in the literature of the hydrocarbon compounds. The following pages they are treated for the most part with great brevity.

1. Simple Hydrocarbons. Chiefly members of the Paraffin Series $\text{C}_n\text{H}_{2n+2}$.

Acetylene. In which name is crystals. Perhaps a polymer of methane CH_4 . Found in brown and black rocks and in coal.

Ethane. Molecular formula C_2H_6 . Colorless gas or liquid. Taken from the yellowish liquid C_2H_4 and C_2H_2 from the coal measures near Merckville in Pennsylvania. Found in the coal measures near Merckville in Pennsylvania.

Propane. Molecular formula C_3H_8 . Colorless gas or liquid. Taken from the coal measures near Merckville in Pennsylvania.

Butane. Molecular formula C_4H_{10} . Colorless gas or liquid. Taken from the coal measures near Merckville in Pennsylvania.

Pentane. Molecular formula C_5H_{12} . Colorless gas or liquid. Taken from the coal measures near Merckville in Pennsylvania.

Hexane. Molecular formula C_6H_{14} . Colorless gas or liquid. Taken from the coal measures near Merckville in Pennsylvania.

Paraffin, $C_{18}H_{38}$. Same as anthracene. In delicate needles. $C = 1.43$. Negative refraction. It is a solid, colorless, odorless, and tasteless substance, which is insoluble in water, but soluble in alcohol, ether, and benzene. It is a natural product, found in the Dräbenhohle near Mixnitz in Styria, Austria.

The following are all more complete lists of hydrocarbon compounds of great importance from a commercial point of view.

Petroleum. Natural, Petroleum Mineral, Petroleum.

1. Petroleum. The crude state of hydrocarbon when varying widely in color from colorless to dark brown, and in consistency from liquid to solid. It is a natural product, found in the Dräbenhohle near Mixnitz in Styria, Austria. It is a natural product, found in the Dräbenhohle near Mixnitz in Styria, Austria. It is a natural product, found in the Dräbenhohle near Mixnitz in Styria, Austria.

Crude petroleum consists for the most part of members of the paraffin series, but it also contains some members of the olefin series. It is a natural product, found in the Dräbenhohle near Mixnitz in Styria, Austria. It is a natural product, found in the Dräbenhohle near Mixnitz in Styria, Austria. It is a natural product, found in the Dräbenhohle near Mixnitz in Styria, Austria.

Petroleum is a mixture of many different hydrocarbons, and its composition varies greatly. It is a natural product, found in the Dräbenhohle near Mixnitz in Styria, Austria. It is a natural product, found in the Dräbenhohle near Mixnitz in Styria, Austria. It is a natural product, found in the Dräbenhohle near Mixnitz in Styria, Austria.

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Asphaltum. Natural, Asphalt.

Asphaltum is a mixture of many different hydrocarbons, and its composition varies greatly. It is a natural product, found in the Dräbenhohle near Mixnitz in Styria, Austria. It is a natural product, found in the Dräbenhohle near Mixnitz in Styria, Austria. It is a natural product, found in the Dräbenhohle near Mixnitz in Styria, Austria.

Asphaltum belongs to rocks of the same age. The most abundant members are in part, but they are generally of a more or less solid nature. It is a natural product, found in the Dräbenhohle near Mixnitz in Styria, Austria. It is a natural product, found in the Dräbenhohle near Mixnitz in Styria, Austria. It is a natural product, found in the Dräbenhohle near Mixnitz in Styria, Austria.

Cracking or Cracking Coal. A bituminous coal which softens and becomes pasty or molten at a certain temperature when heated at the temperature of 300°C . or higher, and is then distilled with the removal of the gas. The resulting liquid is called *cracking oil*, and the residue is called *cracking coal*. The cracking process is a chemical change, and the products are different from the original coal. The cracking process is a chemical change, and the products are different from the original coal.

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APPENDIX A

ON THE DRAWING OF CRYSTAL FIGURES

In the representation of crystals by figures it is customary to draw their edges as if they were projected upon a horizontal plane. Two kinds of projections are used, the orthographic, which is that of perspective laid on a flat surface, and the isometric, where the faces and edges are given just as they are in position. The accuracy of these projections can be more important than that of the lines, since a perspective drawing is not a true representation of the object. The drawing of crystals in the latter case can be made to be at once clearer and more convincing than in the former, when the latter are constructed in the manner usual at the present day.

In the present paper, we study the very special case of the simple cubic lattice. It is the simplest ideal crystal which is most easily modeled. In this case the crystal with the full geometrical symmetry has been examined on pgs. 1-14 of [1] and on pgs. 1-14 of [2].

14 The general concepts of evolution are made either by considering the flower apart a
 15 subject in its own right, or by regarding the flower as a part of the plant, and then
 16 for a part of the whole of the organism. In the former case the flower is treated
 17 for a long time as a part of the whole of the organism, and then the whole of the
 18 organism is treated as a part of the whole of the organism. The former case is the
 19 only one in which the flower is treated as a part of the whole of the organism.
 20 of a certain kind of organism, and the whole of the organism is treated as a part
 21 of a certain kind of organism. In this case the flower is treated as a part of the
 22 whole of the organism, and the whole of the organism is treated as a part of the
 23 whole of the organism. The former case is the only one in which the flower is
 24 and outcomes are described in the

DRAWING OF CRYSTALS USING PROJECTIONS OF THEIR CRYSTAL AXES

PROJECTION OF THE AIR

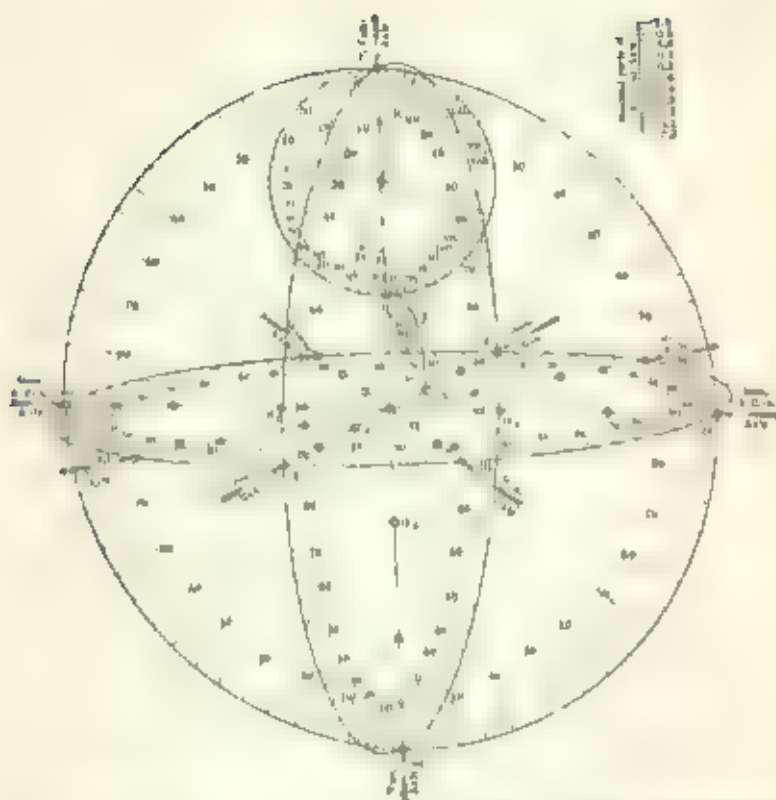
[illegible]

Isometric System - The following system is the making of the projection of the object from the front, top, and side views.

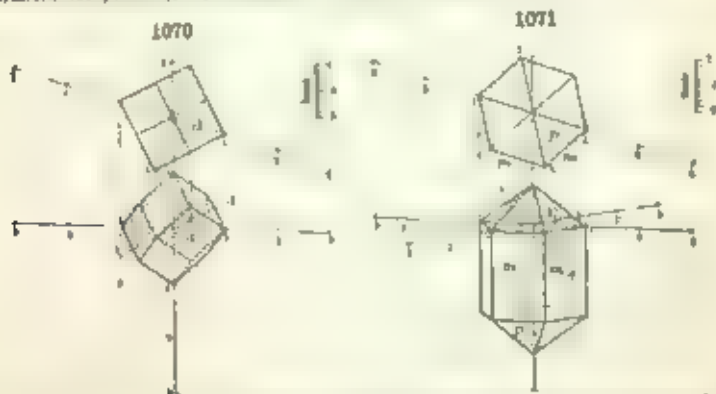
Fig. 107^b will make out the projection of the cube. The projection of the cube is based. Fig. 107A is an isometric drawing of the cube as seen from above. A cube is two positions, one as a cube and one as a rectangular prism. The other $ABCD$, after a rotation of 90° to the left, is a rectangular prism. The isometric drawing here through a rotation of the axes. Fig. 107B is likewise an orthographic projection of a cube in the position of $ABCD$ of A when viewed from in front. The cube or prism of view is being in a level with the vertical. The position of the cube is the width of the face of $ABCD$ is indicated that of the front face AB that being in

* The various Proteus crystal anisotropy apparatus may be obtained from the Mineralogical Laboratory of the Sheffield Science School of York University, New Haven, Connecticut.† Opt. crystal drawing. *Am. J. Sci.*, 19, 39, 1965.

1069



Protractor for plotting crystallographic axes, one-third natural size (after Penfield)



Schemes of the engraved axes of the isometric and hexagonal systems, one-sixth natural size (after Penfield)

and c axes must be modified. The desired point upon the c axis can be obtained as described above. In the case of the a axis the required point can be found by the same method of construction. If, as in the case in the stereonet charts, a plan of the ab orthographic horizontal axis is given in a 45° view, the desired length can be laid off directly upon the a axis in this orthographic projection by means of the desired scale and both projected vertices lie exactly upon the stereographic projection. Or the proper distance can be laid off on the vertical axis and then, by means of a line drawn from this point parallel to a line joining the extremities of the a and b axes of the isometric projection, the proper proportional part of the a axis can be determined by intersection.

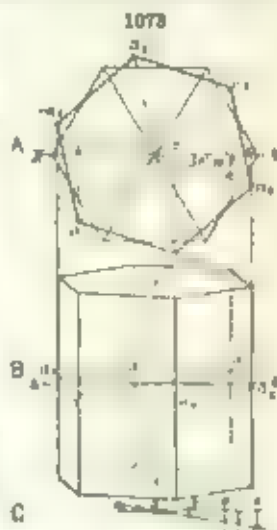
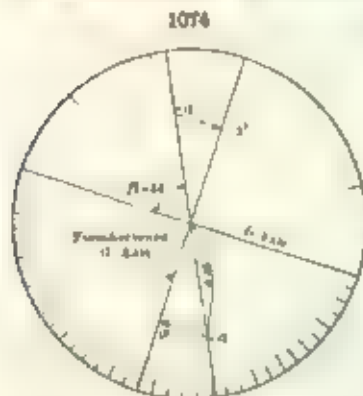
Hexagonal System. For projecting the hexagonal axes onto the stereonet, the same principle may be applied as if as were employed in the construction of the isometric axes. Fig. 1073 is an orthographic projection, a plan of a hexagonal prism in two positions, one of which is a_1 , etc., after a rotation of $18^\circ 26'$ from what may be called a normal position. In Fig. 1073B the extremities of the horizontal axes of A have been projected down upon the horizontal construction line AB and a vertical line, which will be one of the axes A_1 in A is located below the line AB in the orthographic projection, the distances from AB being measured if necessary and used in Fig. 1073C as a scale for projecting the distances which the extremities of the axes are dropped. The vertical axis in Fig. 1073B has been given, the same length as the axes of the prism.

Monoclinic System. In the case of the monoclinic axes the a axis and length of the a axis must be determined in our case. The axial chart, Fig. 1074, can be given conveniently used for this purpose. The angles in the figure between A, B, C give the trace of the axes if the angles are taken as they are rotated in the 45° plane. To find, therefore, the inclination of the a axis it is only necessary to lay off the angle a by means of the goniometer given on this chart. The a axis length of the a axis may be determined in various ways. The plan of the axes given at the top of the chart may be used for this purpose. Fig. 1074 will illustrate the method of general use as applied in the case of orthoclase where $\beta = 64^\circ$ and $\alpha = 90^\circ$.

The inclination of the a axis is determined as follows and then its length can be projected vertically downward upon the inclined a axis, the direction of which has been previously determined as described above.

Triclinic System.—In the construction of triclinic axes the inclination of the a axis and its length are determined in exactly the same manner as described in the preceding paragraphs in the case of the monoclinic system. The construction of the b axis is determined as follows. The vertical plane of the b axis is revolved about the a axis through such an angle as will conform to the angle between the planes 100 and 010 . Care must be taken to note whether this plane is to be revolved toward the front or toward the back. If the angle between the normals to 100 and 010 is greater than 90° the right-hand end of this plane is to be revolved toward the front. Fig. 1075, which is a simplified version of the axial chart, shows the necessary construction under the use of rhodochrosite which has $\alpha = 10^\circ$ and $\beta = 103^\circ 18'$.

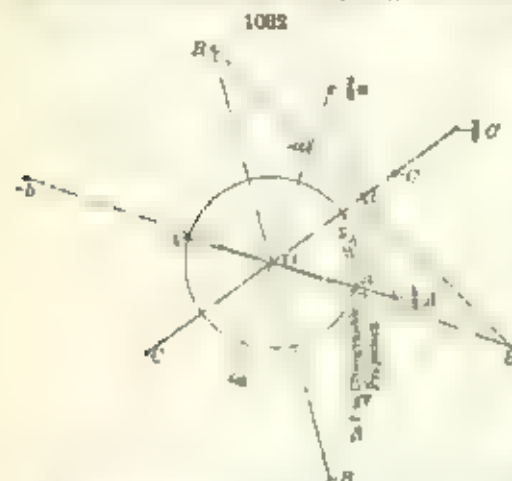
The plane of the b axis will pass through the point p while p is $64^\circ 26'$ from $-a$. To locate the point p , which is the point where the a axis would intersect from the sphere, draw through the point p two or more chords from p to w where the vertical ellipses of the chart cross the horizontal ellipses, as aw , ap , bp , in Fig. 1075. Then



Development of the axes of the hexagonal system in a horizontal and vertical projection after Pinchard.

to obtain the direction of the b axis in the case of rhodochrosite which has $\alpha = 10^\circ$ and $\beta = 103^\circ 18'$. The plane of the b axis will pass through the point p while p is $64^\circ 26'$ from $-a$. To locate the point p , which is the point where the a axis would intersect from the sphere, draw through the point p two or more chords from p to w where the vertical ellipses of the chart cross the horizontal ellipses, as aw , ap , bp , in Fig. 1075. Then

crystal. The angle from $c(001)$ to $c(00\bar{2})$ equals $63^\circ 7'$. In order to make the face f vertical, the vertical axis must be inclined at an angle of $30^\circ 53'$ or the angle between the c axes of the two individuals composing the twin would be double this or $63^\circ 46'$. These



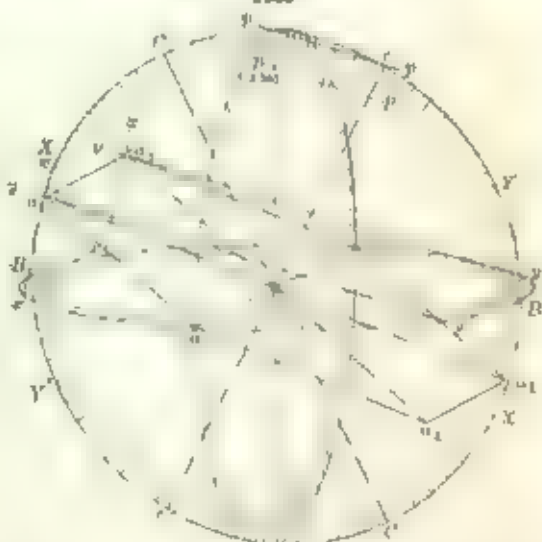
relations are shown in Fig. 1084. As indicated in Fig. 1085 the position of these axes, c and c' in the figure are easily obtained at inclinations of $20^\circ 53'$ by use of the gnomon of the vertical ellipse that passes through B and $-B$. The points X and Y are the intersections with this ellipse of the two planes containing the a_1 , a_2 and a_3 axes in their respective inclined positions, the angles $\angle BX$, $\angle BY$, and $\angle XY$ and $\angle BY$ being in each case equal to $20^\circ 53'$. In order to have the twinning plane occupy a position parallel to the 010 plane of an orthorhombic crystal it is necessary to revolve the axes so that one of the hexagonal axes of the crystal will be parallel to the c axis of the orthorhombic system, as a_1 , a_2 in Fig. 1085. The two other hexagonal axes corresponding to the axes c and c' therefore lie in a plane which

contains X and have such position that they will make angles of 60° with a_1 , a_2 . The construction necessary to determine the axes of these axes is as follows: Draw the two chords of the circle XX' and YY' through points that are 60° from $-a_1$ and a_1 and parallel to the direction of a_2

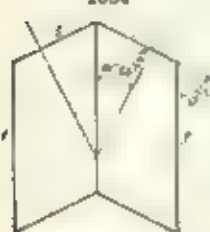
1083



1085



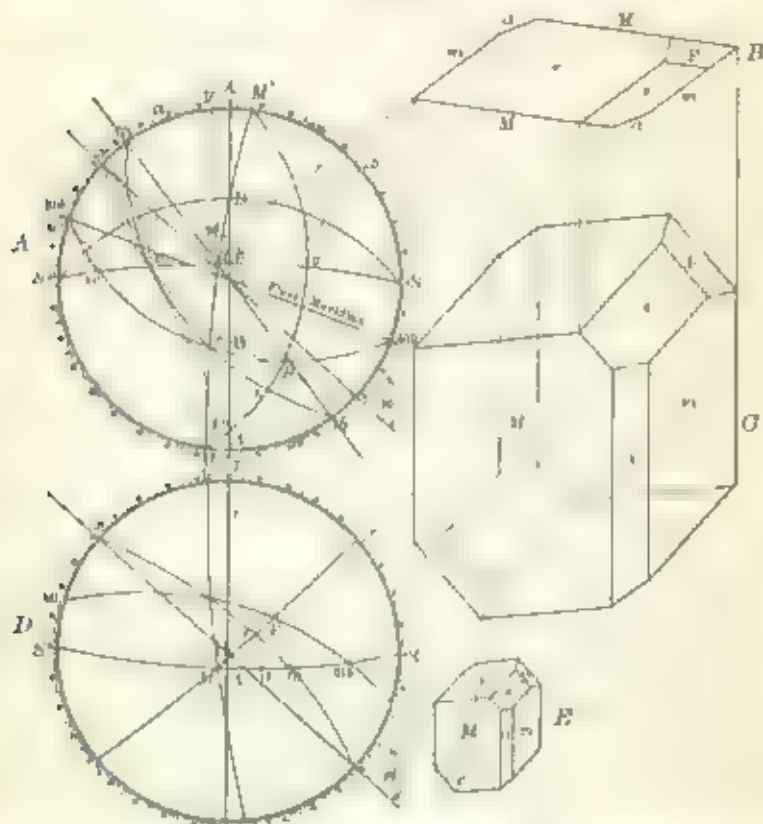
1084



chord that would pass through $-B$ and X . In a similar way draw the two chords YY' through the second pair of points that are 60° from $-a_1$ and a_1 , parallel to the direction of a_2 . The two chords XX' and YY' intersect at points X and Y . The intersections of these two sets of chords determine the points a_1 and a_2 , which are the axes of these respective axes. The hexagon shown in the figure connects the ends of the a_1 , a_2 and a_3 axes that as in a

reason for this is not easily comprehended from A, but if it is imagined that the projection is revolved 90° about an axis $l-l'$, so as to bring l at the center the important poles and great circles to be considered will appear as in Fig. 1087 where P and C are the poles, respectively, of the great circles ESB' and ASB , and z is 45° from S as in Fig. 1086A. It is evident from the symmetry of Fig. 1087 that a plane surface meeting at C , P and z will be tangent to the great circle ASB and the distance SC and SP are equal. Now a plane passing through C , P , z and z' , if extended, would intersect the sphere as a small

1086

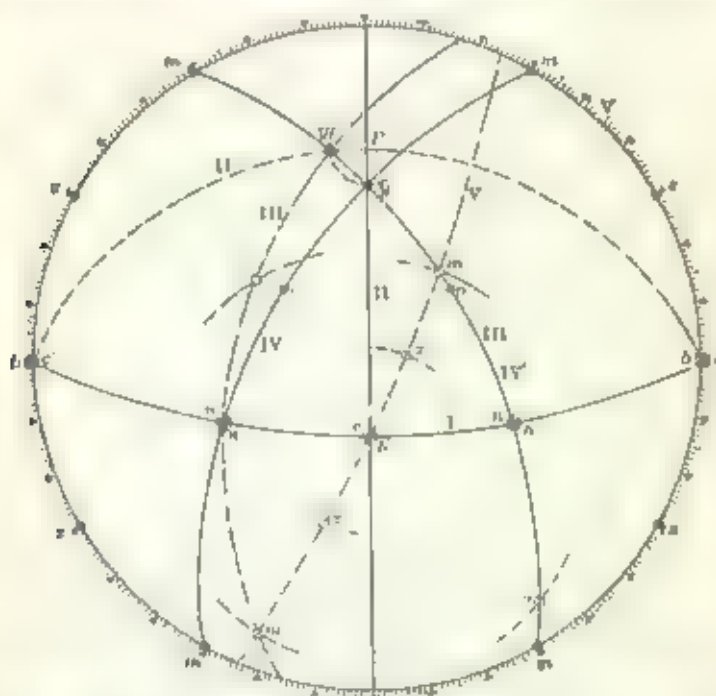


Development of a plane and parallel perspective of figure 1085A into the triclinic system, from a stereographic projection (after Penck)

circle, shown in the figure, but since this circle passes through C , which in Fig. 1086A is the pole of the stereographic projection, it would be tangent to $l-l'$ at C . It will be projected in Fig. A as a straight line, drawn through C and l . Since the stereographic is from the plane of projection of all planes that pass through the point of contact of the projection will appear as straight lines. In Fig. 1087 B is located midway between b and A . BSB' is a great circle, and W 40° from C , or 40° from l . It is now evident from the symmetry of the figure that a great circle through W and z will intersect the great circle ASB at the points S and S' are small. Transferring the bearing relations of Fig. 1086A W 40° from l , is the pole of the great circle ESB' , and again, in a line through W or l is tangent at z . However, it is not necessary to draw the great circle through W and z to locate the point z' on the graduated circle. By centering the Penckian transparent from circle projector (Fig. 85, p. 55,

be easily determined. On this arc, III, o and m must also lie. Their positions are most easily determined by drawing arcs of small circles about o with the required radii, $b \wedge o = 63^\circ 8' - b \wedge m = 59^\circ 22'$, and the point at which they intersect are III locate the position of the poles o and m . At the same time the corresponding points on IV can be located, it being noted that IV and III are the same arc. But one other form remains to be transposed, the prism x . We have already o' and m located in I as a single center with the aid of the great circle projection to determine the position of the great circle arcs on which they lie. Then an arc is drawn about o with the proper radius $b \wedge x = 21^\circ 24'$. Its intersections of arcs by its intersections with arcs are the positions of the poles of the x faces.

1088



It may be pointed out that if it should be desired to make use of the methods of the gnomonic projection for the drawing of the lines represented below the stereographic projection of the same may be easily translated into gnomonic projection by folding the circular diagram from the center to the poles and projecting to the poles by the use of the stereographic protractor, Fig. 90, p. 61.

3. USE OF THE GNOMONIC PROJECTION

As an illustration, the method of drawing a simple combination of beryl has been chosen. The faces shown in Fig. 1088 are c 01, m 10, o 31 and d 101. The position of the poles in the gnomonic projection is shown in A, where, as in Fig. 1088 A, the great circle on which o lies is at 20° from the horizontal direction SS. The poles of the faces m and o are located at 5 and 1 respectively. Fig. 1088 A and B the gnomonic projection at infinity. The projection of the faces c and d is at right angles to a line joining the poles of the faces, shown in figures A and B by the direction at 90° to the line joining m and o .

The parallel perspective view, 1088 C is an orthographic projection, compare Figs. 1086 A and C, drawn on a plane passing through S and S' and intersecting the sphere at

APPENDIX B

TABLES USEFUL IN THE DETERMINATION OF MINERALS

This Appendix contains a series of tables, more or less complete, of names arranged according to broadest and most basic or ethnic group and ethnographic or racial character. These, it is believed, will be of service not only to the student, but also to the scholar, researcher.

The first part of the meaning of the mineral names indicates their relative importance. Table 1 is a complete list of the species names in this book arranged in descending order to the predominant basic anion with the cations and accessory anions in parentheses following. The results of Minerals were given according to their system of I and on the Table can be made to give a very different but it is often to give such as a number of species.

For an extensive system of themes and exercises based on the work of Frobenius, Frahm and others, see the appendix.

TABLE I. MINFILAM ARRANGED ACCORDING TO CHEMICAL COMPOSITION

The following data include a checklist, descriptive numbers, species arranged first according to their important plant associates and secondly according to their animal associates. A given animal contains two or more plants, whereas its name is repeated in the appropriate sections.

ALUMINIUM

NOTE. — Aluminum is of such common occurrence among the silicate minerals that it is represented as a part of these silicate minerals. Therefore only those rare cases which are constantly recognized minerals are included in the following list.

Cryolite, Na_3AlF_6
 Cry. *decahydrate*, $\text{Na}_3\text{F}_3\text{Al}_2\text{F}_6 \cdot 2\text{H}_2\text{O}$
 Kyanite, Al_2SiO_5 , trichlorite
 Sil. *ortho*, Al_2SiO_5
 Chloromelanite, $\text{AlCl}_3 \cdot 6\text{H}_2\text{O}$
 Fluorapatite, $\text{Ca}_5(\text{F}, \text{Cl})_3(\text{PO}_4)_3$
 Fluorapatite, Thomsenite, $\text{NaF} \cdot \text{CaF}_2 \cdot \text{AlF}_3$
 H₂
 Cleveite, $\text{CaF}_2 \cdot \text{AlF}_3 \cdot \text{H}_2\text{O} \cdot \text{H}_2\text{O}$
 Rastbachite, $\text{Na}_2\text{Mg}_2\text{F}_4\text{Al}_2\text{F}_6 \cdot 2\text{H}_2\text{O}$
 Zinkite, $\text{Zn}_2\text{Mg}_2\text{Cl}_2\text{Al}_2\text{Cl}_2 \cdot 3\text{H}_2\text{O}$
 Zinkite, $2\text{CaF}_2 \cdot \text{AlF}_3 \cdot \text{H}_2\text{O} \cdot \text{CaSO}_4 \cdot 2\text{H}_2\text{O}$
 Trisulphate, $4\text{AlCl}_3 \cdot \text{Al}_2\text{SO}_4 \cdot 4\text{H}_2\text{O}$
 Corundum, Al_2O_3
 Rastbachite, $\text{Al}_2\text{O}_3 \cdot \text{Fe}_2\text{O}_3 \cdot \text{MgO} \cdot \text{TiO}_2$
 Spinel, $\text{MgO} \cdot \text{Al}_2\text{O}_3$
 Hercynite, $\text{FeO} \cdot \text{Al}_2\text{O}_3$
 Chrysotile, $\text{ZnO} \cdot \text{Al}_2\text{O}_3$
 Garnet, $(\text{Mn}, \text{Fe}, \text{Mg})_3(\text{O}, \text{Al})_4\text{Fe}_2\text{O}_4$
 Chrysoberyl, $\text{BeO} \cdot \text{Al}_2\text{O}_3$
 Diaspore, $\text{Al}_2\text{O}_3 \cdot \text{H}_2\text{O}$
 Bostonsite, $\text{Al}_2\text{O}_3 \cdot \text{H}_2\text{O}$
 Kyanite, $\text{Al}_2\text{O}_3 \cdot \text{H}_2\text{O}$
 Bostonsite, $\text{Al}_2\text{O}_3 \cdot \text{H}_2\text{O}$
 Chrysoberyl, $\text{Al}_2\text{O}_3 \cdot \text{H}_2\text{O}$
 Staurolite, $\text{Al}_2\text{O}_3 \cdot \text{H}_2\text{O}$
 Staurolite, $\text{Al}_2\text{O}_3 \cdot \text{H}_2\text{O}$
 Diopside, $\text{Ca} \cdot \text{Al}_2\text{Si}_2\text{O}_6$
 Diopside, $\text{Na} \cdot \text{Al} \cdot \text{Si}_2\text{O}_6$
 Acuminatohydroxide, Hydroxide , $\text{Ca} \cdot \text{Al}_2\text{Si}_2\text{O}_6$
 Hydroxide, $\text{Mg} \cdot \text{Ca} \cdot 6\text{Mg} \cdot \text{OH}_2 \cdot 2\text{Al}_2\text{O}_3$
 Zinkite, $\text{Al} \cdot \text{OH}_2 \cdot \text{Cl} \cdot \text{Al}_2\text{Si}_2\text{O}_6$
 Topaz, $\text{Al} \cdot \text{F} \cdot \text{OH}_2 \cdot \text{Si}_2\text{O}_6$
 Anhydrite, Al_2O_3
 Staurolite, Al_2O_3
 M. *ortho*, Al_2O_3
 Kyanite, Al_2O_3

ARSENIC

NOTE. — The arsenates are not included in this list.

NATIVE ARSENIC, As .

Almonite, $SiAs_2$.

Reichenite, As_2S_3 .

Orpiment, As_2S_3 .

Jeremite, a double of arsenic.

Arsenopyrite, $FeAsS$.

Arsenolite, Claustolite, As_2O_3 .

BARIUM

Hollandite, manganese of Mn, Ba, Fe .

Barroite, $Ba_2Cl_2F_2$.

Winklerite, $BaCO_3$.

Barroite, $BaCO_3$.

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BISMUTH

NATIVE BISMUTH, Bi .

Bismuthite, Bi_2S_3 .

Bismuthite, Bi_2S_3 .

Bismuthite, Bi_2S_3 .

Bismuthite, Bi_2S_3 .

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Bismuthite, Bi_2S_3 .

Bismuthite, Bi_2S_3 .

Bismuthite, Bi_2S_3 .

Bismuthite, Bi_2S_3 .

Bismuthite, Bi_2S_3 .

Bismuthite, Bi_2S_3 .

BORON

NOTE. — The borates are not included in this list.

Boracite, B_2O_3 .

Boracite, B_2O_3 .

Boracite, B_2O_3 .

Boracite, B_2O_3 .

Boracite, B_2O_3 .

Boracite, B_2O_3 .

Boracite, B_2O_3 .

Boracite, B_2O_3 .

Boracite, B_2O_3 .

Boracite, B_2O_3 .

Boracite, B_2O_3 .

Boracite, B_2O_3 .

Boracite, B_2O_3 .

Boracite, B_2O_3 .

Boracite, B_2O_3 .

Boracite, B_2O_3 .

Boracite, B_2O_3 .

Boracite, B_2O_3 .

Boracite, B_2O_3 .

Boracite, B_2O_3 .

Boracite, B_2O_3 .

Boracite, B_2O_3 .

Boracite, B_2O_3 .

Boracite, B_2O_3 .

Boracite, B_2O_3 .

Boracite, B_2O_3 .

Boracite, B_2O_3 .

Boracite, B_2O_3 .

Boracite, B_2O_3 .

Boracite, B_2O_3 .

Boracite, B_2O_3 .

Boracite, B_2O_3 .

Boracite, B_2O_3 .

Boracite, B_2O_3 .

Boracite, B_2O_3 .

BERYLLIUM

Beryllite, BeO .

Beryllite, BeO .

Beryllite, BeO .

Beryllite, BeO .

Beryllite, BeO .

Beryllite, BeO .

Beryllite, BeO .

Beryllite, BeO .

Beryllite, BeO .

Beryllite, BeO .

Beryllite, BeO .

Beryllite, BeO .

Beryllite, BeO .

Beryllite, BeO .

Beryllite, BeO .

Beryllite, BeO .

Beryllite, BeO .

Beryllite, BeO .

Beryllite, BeO .

Beryllite, BeO .

Beryllite, BeO .

Beryllite, BeO .

CADMIUM

Greenockite, CdS .

Cadmiumoxide, CdO .

Cadeite, $CdCO_3$.

CERIUM

Fluorite, $2CeO_2 \cdot 2Al_2O_3 \cdot 8H_2O$.

Rhodolite, $Al_2O_3 \cdot Ce_2O_3$.

CALCIUM

Orthamite, CaS .

Fluorite, CaF_2 .

Yttriumite, CaF_2 with YF_3 .

Yttriumite, CaF_2 with YF_3 .

[illegible][illegible]

LEAD

[illegible]

Bodenbenderite, Silicate and titanate of Al,
Y, Mn

Boehmite, $H_2FeMg_2Si_2O_7$
Jugosta, $H_2Mg_2Si_2O_7 \cdot 3H_2O$
Garnophyllite, $7MnO \cdot 3Fe_2O_3 \cdot 8H_2O$
Alargite, $KMg_2Si_2O_7$
Dixontite, $MnSi_2O_7 \cdot 2MnO \cdot 10H_2O$
Muscovite, $21MnMg_2Zn_2O_{10}Si_2O_7$
 $\cdot 4H_2O \cdot 2H_2O$

Bomontite, $H_2MnSi_2O_7$
Euxipte, $Mg_2Si_2O_7 \cdot H_2O$
Hedgelandite, $3ZnMg_2Si_2O_7 \cdot H_2O$
Gangue, Hydrous Mn, Mg, Zn, silicate
Necrota, Hydrous Mn, Fe, silicate
Bemite, Hydrous Mn, Ca, Na, silicate
Muscovite, $6MnCaMg_2O_7Fe_2O_3 \cdot 2H_2O$

Astrakhanite, Na, K, Fe, Mn, Ti silicate
Necrota, Fe, Mn, Na silicate
Cassidite-Tantalite, (Fe, Mn)
 (Ti, Ta, O_2)

Tantalite, Fe, Mn, Nb, Ta, O_2
Hedgelandite, Y, Fe, Mn, Ca silicate
Bemite, Ca, Na, Mg, Mn, As, O_2
Lactonite, Ca, Mg, Fe, O_2
Necrota, Na, Mn, O_2
Gangue, Fe, Mn, Ca, O_2
Tantalite, $Fe, K, O_2, R = Fe, Mn$
Tantalite, $Fe, O_2, R = Mn, Fe$
Necrota, Mn, O_2
Astrakhanite, $2Mn, O_2, Mn, O_2$
Necrota, Fe, Mn, Ca, O_2
Necrota, Fe, Mn, Ca, O_2
Tantalite, Fe, Mn, Ca, O_2
Lactonite, $Na, Ca, Mn, O_2, Fe, O_2, O_2$

Pyrochlore, $4MnMg_2O_7 \cdot 2H_2O$
Bemite, Fe, Mn, O_2
Lactonite, Ca, Mg, Fe, O_2
Necrota, $2MnMg_2O_7 \cdot 2H_2O$
Astrakhanite, $5MnO \cdot 2MnMg_2O_7 \cdot 2H_2O$

Fluorite, Mn, As, O_2
Hedgelandite, Al, Mn, O_2
Bemite, Ca, Mg, O_2
Astrakhanite, Mn, Ca, O_2

Manganite, Mn, O_2
Dixontite, $Hydrous Mn, Fe, Na$
Euxipte, Mg, O_2
Hedgelandite, Ca, Mg, O_2
Fluorite, Ca, Mg, O_2
Astrakhanite, Mn, Mg, O_2
Wadsworthite, Mn, Mg, O_2
Hedgelandite, Mn, O_2
Fluorite, Mn, O_2
Stewartite, $3Mn, Fe, O_2$
Purpurite, $2Fe, Mn, O_2$
Stewartite, Fe, O_2
Lactonite, Ca, Mg, O_2
Lactonite, Ca, Mg, O_2
Hedgelandite, Mn, O_2
Hedgelandite, Mn, O_2

Chlorophosphate, $10(Zn, Mn)O \cdot 4H_2O$
Hedgelandite, $4MnO \cdot 4ZnO \cdot 4H_2O$
Kocherite, $2AlO_3 \cdot 2Mn, Fe, O_2$
Kocherite, Mn, Fe, Ca, O_2

Cataprite, $14MnFeO_2 \cdot Al, Fe, O_2$

Scandite, Hydrous Mn borophosphate
Scandite, $11MnO \cdot 2Mg, O_2$
Purpurite, Mg, O_2
Manganite, Mn, O_2
Scandite, Mn, O_2
Lactonite, Mn, O_2
Manganite, Mn, O_2
Manganite, $Hydrous Mn, Zn, O_2$
Astrakhanite, Mn, O_2
Dixontite, Zn, Fe, Mn, O_2

MERCURY

Native Mercury, Hg
Astrakhanite, Ag, Hg
Manganite, Hg, O_2
Fluorite, Hg, O_2
Oxide, Hg, O_2
Chloride, Hg, Cl_2
Cinnabar, HgS
Lactonite, Hg, O_2
Chloride, Hg, Cl_2
Hydrous, Hg, O_2
Fluorite, Hg, O_2
Tantalite, Hg, O_2
Manganite, $Hydrous Hg, NH_4, chloride$
Manganite, Hg, O_2
Astrakhanite, Hg, O_2

MOLYBDENUM

Molybdenite, MoS_2
Molybdenite, MoS_2
Fluorite, Ca, Mo, O_2
Chloride, Mo, O_2
Wadsworthite, $4Mn, O_2$
Hedgelandite, Fe, O_2
Kocherite, Hg, O_2

NICKEL

Auriferite, Fe, Ni
Josephite, Fe, Ni
Manganite, Ca, Ni
Purpurite, R, O_2
Pyrochlore, Fe, O_2
Manganite, Ni, O_2
Hedgelandite, Ni, O_2
Hedgelandite, Ni, O_2
Fluorite, Ni, O_2
Lactonite, Ca, Ni, Fe, O_2
Hedgelandite, Fe, Ni, O_2

[illegible]

TRANSITION

Tangentville, W. Va.
 1. Tangentville, W. Va.
 2. Tangentville, W. Va.
 3. Tangentville, W. Va.
 4. Tangentville, W. Va.
 5. Tangentville, W. Va.
 6. Tangentville, W. Va.
 7. Tangentville, W. Va.
 8. Tangentville, W. Va.
 9. Tangentville, W. Va.
 10. Tangentville, W. Va.

1 RANDOM

[illegible][illegible]

ANALYSTS

[illegible]

II. CRYSTALLIZATION TETRAGONAL

A. LUSTER NONMETALLIC

| | Specific Gravity | Hardness | | Specific Gravity | Hardness |
|-------------------|------------------|----------|--------------|------------------|----------|
| Aegirine | 2.3-2.4 | 4.5-5 | Xenotime | 4.05-4.50 | 4-5 |
| Wernerite | | | Thurstonite | 3.7-4.1 | 4.5-5 |
| <i>synchroite</i> | 2.00-2.75 | 5.5-6 | Zircon | 4.08-4.7 | 7-8 |
| Muscovite | 2.7-2.74 | 5-6 | Monazite | 5.0-5.4 | 4.5-5 |
| Vanadinite | 5-5.45 | 5-5 | Fluorapatite | 3.1-3.9 | 3.75-3 |
| Tremolite | 3.0-3.5 | 5-5 | Calcite | 2.4-2.8 | 3 |
| Octahedrite | 5.8-6.5 | 5.5-6 | Wulfenite | 5.6-6.4 | 2.75-3 |
| Barite | 4.0-4.25 | 6-6.5 | Chromite | 4.8-5.1 | 6 |

B. LUSTER METALLIC AND SEMIMETALLIC

| | Specific Gravity | Hardness | | Specific Gravity | Hardness |
|--------------|------------------|----------|------------|------------------|----------|
| Chromopyrite | 4.1-4.3 | 3.5-4 | Pyrrhotite | 4.7-4.85 | 5-5 |
| Pyrite | 4.9-5.05 | 6-6.5 | Hexamite | 4.7-4.82 | 6-6.5 |

III. CRYSTALLIZATION HEXAGONAL*

Rhombohedral species are designated by a letter R

A. LUSTER NONMETALLIC

| | Specific Gravity | Hardness | | Specific Gravity | Hardness |
|------------------|------------------|----------|-------------------|------------------|----------|
| Calcite R | 2.05-2.17 | 4-5 | Trigonalite, R | 2.36-2.40 | 2-2.5 |
| Clinochalcite R | 2.08-2.10 | 5-5 | Apatite | 3.17-3.23 | 5 |
| Hexamite R | 2.0-2.1 | 5 | Chalcophane R | 3.29-3.35 | 5 |
| Comenite | 2.4-2.5 | 5-6 | Homoclinohalite R | 3.45-3.60 | 3.5-4.5 |
| Chalcophyllite R | 2.4-2.60 | 5 | Siderite R | 3.8-3.95 | 3-3.5 |
| Nacrite | 2.5-2.65 | 4.5-5 | Chalcantite R | 3.95-4.10 | 5 |
| Quartz R | 2.65 | 7 | Wulfenite R | 3.94-4.10 | 6-6 |
| Wollast | 2.7-2.780 | 7.5-8 | Synchroite R | 4.0-4.15 | 5 |
| Almandine R | 2.7-2.77 | 3.5-4 | Chalcite R | 4.0-4.15 | 3.5-4.5 |
| Pyrochroite pure | | | Zircon | 4.4-5.7 | 4-4.5 |
| R | 2.9-2.95 | 2-2.5 | Trigonalite | 4.5-5.1 | 3.5-4 |
| Calcite R | 2.74 | 5 | Vanadinite | 4.6-4.85 | 5 |
| Diopside R | 2.8-2.9 | 3.5-4 | Malachite | 4.6-4.75 | 3.5 |
| Aegirine R | 2.95-3 | 5-6 | Chromite, R | 4.08-5.2 | 2-2.5 |
| Phenacite R | 2.97-3.0 | 5-5.5 | | | |

* Some pseudo-hexagonal species are omitted.

V CRYSTALLIZATION MONOCLINIC

A. LUSTER NONMETALLIC

| | Specific Gravity | Hardness | | Specific Gravity | Hardness |
|--------------|------------------|----------|------------|------------------|----------|
| Muscovite | 1.48 | 1.5-2 | Erythrite | 2.06 | 1.5-2.5 |
| Berax | 1.69-1.72 | 2-2.5 | Margarite | 2.99-3.08 | 3.5-4.5 |
| Muscovite | 1.90 | 2 | Atokite | 2.46-2.4 | 3-6 |
| Calcianite | 1.94 | 2-3 | Lazurite | 3.08 | 5-6 |
| Stibite | 2.10-2.20 | 3.5-4 | Epidote | 3.10 | 7.5 |
| Selenite | 2.16-2.4 | 5-5.5 | Chrysotile | 3.10-3.11 | 0.4-5 |
| Hemimorphite | 2.18-2.22 | 3.5-4 | Chrysotile | 3.1-3.2 | 6-6.5 |
| Pyrite | 2.2 | 4-4.5 | Chrysotile | 3.1-3.2 | 6-6.5 |
| Blende | 2.25 | 2.5 | Pyrite | 3.1-3.2 | 6-6.5 |
| Lazurite | 2.25-2.35 | 3.5-4 | Pyrite | 3.3-3.4 | 5-6 |
| Gypsum | 2.31-2.33 | 1.5-2 | Pyrite | 3.5-3.5 | 6-7 |
| Petalite | 2.39-2.46 | 6-6.5 | Pyrite | 3.5-3.55 | 6-6.7 |
| Fluorite | 2.44-2.5 | 4.5 | Pyrite | 3.40 | 6 |
| Serpentine | 2.50-2.65 | 2.5-4 | Pyrite | 3.44-3.45 | 6 |
| Orthoclase | 2.57 | 6 | Pyrite | 3.4-3.5 | 5-5.5 |
| Yugawite | 2.68-2.68 | 1.5-2 | Pyrite | 3.5-3.55 | 6-6.5 |
| Kyanite | 2.6-2.63 | 2-2.5 | Pyrite | 3.52-3.57 | 6-6.5 |
| Orthoclase | 2.65-2.78 | 2-2.5 | Pyrite | 3.7-3.73 | 8-8.4 |
| Pectolite | 2.68-2.78 | 5 | Pyrite | 3.7-4.2 | 5-5.6 |
| Chrysotile | 2.7-2.8 | 2-2.5 | Pyrite | 3.6-4.03 | 8-8.4 |
| Muscovite | 2.7-2.8 | 2-2.5 | Pyrite | 4.0-4.6 | 4-6.7 |
| Leucite | 2.8-2.9 | 3-3.4 | Pyrite | 4.10-4.30 | 2-5.3 |
| Pyrite | 2.7-3.1 | 3-3.4 | Pyrite | 4.0-5.3 | 5-5.5 |
| Pyrite | 2.78-2.85 | 2-2.5 | Pyrite | 5-5.45 | 2-5 |
| Pyrite | 2.78-2.90 | 1-2 | Pyrite | 5.9-6.1 | 2-5.3 |
| Pyrite | 2.88 | 2-2.5 | Pyrite | 5.6-5.25 | 2-4 |
| Pyrite | 2.8-2.9 | 4-5.5 | Pyrite | 5.26-5.44 | 2-5 |
| Pyrite | 2.8-3.0 | 1-2 | Pyrite | 6-6.4 | 2-2.5 |
| Pyrite | 2.9-3.1 | 6-6.5 | Pyrite | 7.2-7.5 | 5-5.5 |
| Pyrite | 2.95-3 | 2-5 | | | |

B. LUSTER METALLIC AND SUBMETALLIC

Wollastonite

7.2-7.5

5-5.5

VI. CRYSTALLIZATION TRICLINIC

A. LUSTER NONMETALLIC

| | Specific Gravity | Hardness | | Specific Gravity | Hardness |
|-------------|------------------|----------|-----------|------------------|----------|
| Chalcantite | 2.12-2.30 | 2.5 | Anorthite | 2.74-2.76 | 6-6.5 |
| Muscovite | 2.51-2.57 | 6-6.5 | Anorthite | 3.01-3.09 | 6 |
| Pyrite | 2.62-2.65 | 6-6.5 | Anorthite | 8-27 | 6-6.7 |
| Pyrite | 2.65-2.67 | 6-6.5 | Pyrite | 7.4-3.68 | 5-5.5 |
| Pyrite | 2.68-2.69 | 6-6.5 | Pyrite | 3.56-3.67 | 5-7.25 |
| Pyrite | 2.70-2.72 | 6-6.5 | | | |

Rhombohedral. Angle 77° and 108° Calcite Dolomite, Siderite Rhodochrosite
 Angle not far from 90° Chalcite Magnesite, also Quartz, Hematite.
Sphenohedral. Calcite and siliceous Carbonates, Promante.

IV ORTHORHOMBIC MONOCLINIC AND TRICLINIC SYSTEMS

Prismatic Crystals. METALLIC LUSTRE Schuster, Arsenopyrite, Bournonite, Malganite; Carbonate
 NONMETALLIC LUSTRE Orthorhombic Topaz Staurolite, Andalusite Barite Celestite, Uraltinite Also rhombohedral Pyrophyllite Amphibole Orthoclase, and many others.
 Triclinic crystals are also prominent in aspect. See pp. 434-435.
Tabular Crystals. Barite Cerussite Cassiterite Diaspore Wollastonite Albite
Acicular Crystals. Microcline, Luster Substrate, Hematite, Siderite, Jamesonite; Askinite, and other species.
Nonmetallic Luster. Siderite Natrolite Scapolite, Thomsonite and other Zeolites.
 Also Aragonite Strontianite, from different localities. Also many other species.
Twinned Crystals. The habit of twinning occurring with many species is very characteristic. Reference is made to pp. 179 to 181 and the accompanying figures for a presentation of this subject.

TABLE IV. STRUCTURE OF MASSIVE MINERALS

Fibrous. Fibers arranged. Asbestos amphibole, also the similar asbestosiform variety of serpentinite. Bryozoa, etc. See pp. 181-182.
Fibrous-massive. Asbestos (also Asbestos) Calcite Cryolite Also Aragonite Barite, Cerussite, Arsenite, Hematite, Enstatite, Wollastonite, Diopside, Vivianite. See also 183-184 below.
Fibrous-Radiated. Wavellite Ferriolite, Thomsonite, Natrolite, Sclerite, heulandite and other Zeolites. Cassiterite, Malganite.
Columnar. Microcline, Enstatite, Hematite, Jamesonite, Zinkite, etc.
Nonmetallic Luster. Limestone, also Aragonite. Amphibole, etc. to ground like, etc., Epidote, Zircon, Thomsonite, Wollastonite, Natrolite and other Zeolites, Strontianite; Witherite; Topaz.
 Hydrite has distinct layered structure.
 Fibrous and columnar crystals grow into one another.
Lamellar-Banded. Cryolite, Pyrophyllite, etc.
Faceted. METALLIC LUSTRE Graphite, Molybdenite, Tetradymite, Stannite, etc.
Grouping to
Nonmetallic Luster. Talc, Opuntia, Cryolite, Pyrophyllite, Serpentine.
Micaceous. The Micas, p. 437 and the Heavy Micas, p. 441, and the Chlorites, p. 444.
Also Hematite, Opuntia, Talc, Tourmaline, Andalusite.
Granular. METALLIC LUSTRE Cassiterite, Enstatite, Magnesite. Many sulphides, sulphates, etc., in a variety of other textures, as to a mass and unpalpable.
Nonmetallic Luster. In some varieties, garnet, calcite, hematite.
Botryoidal, mammillary, reniform, etc. METALLIC LUSTRE Hematite, Arsenite, Almandine.
Nonmetallic Luster. Malachite, Prehnite, Smithsonite, Calamine, Chalcocite, Hyacinth, etc. See pp. 181-182, etc.
Stalactitic. METALLIC LUSTRE Limonite, Psilomelane, Marcasite.
Nonmetallic Luster. Cassiterite, Aragonite, Cerussite, Chalcocite.
Granular Cleavable. METALLIC LUSTRE Cassiterite.
Nonmetallic Luster. Calcite, Diaspore, Sphalerite, Fluorite.
Oblate. Cassiterite, Aragonite, Hematite.
Earthy. Nonmetallic Luster. Magnesite, Pyrite.

TABLE V. PHYSICAL CHARACTERS

I CLEAVAGE

Cubic. -- METALLIC LUSTRE. Galena.

Nonmetallic Luster. Heavy Micas. The cleavage of Anhydrite also of Cryolite simulates this. Cf. also Cornusmith, p. 451.

Octahedral — Fluorite; Diamond. Magnetite (also Frankinite) has often distinct octahedral parting.

Dodecahedral — Sphalerite. Also, imperfect. Sodalite. Hauynite.

Rhombohedral. Calcite and other species of the same group. pp. 511-521 angles 75° and 105°.

Square Prismatic (90°) — Selenite, Rutile, Xenotime.

Prismatic (various 75°, 104°, 120°, etc.) — Cerussite, Anglesite 54° and 126°, etc.

Basal — Mica, Lepidolite, Graphite, Molybdenite.

Nonmetallic Luster — Apophane, Topaz, also in Micas and Chlorites, Chalcophyllite, etc. Pyrite is often shown in red basal parting.

Pinacoidal — Metallic luster. Selenite.

Nonmetallic Luster — Gypsum, Urgonite, Eucrase, Diaspore, Silimanite; Hyacinth, Felsspar.

II. HARDNESS

1. Soft Minerals. — The following minerals are comparatively soft, that is, H = 2 or less, they may even be scratched by the finger nail. See further the Tables, pp. 811 to 816.

Metallic Luster — Graphite, Molybdenite, Tetraamite, Sternbergite, Argentite; Naugolite, some of the Native Metals Lead, etc.

Nonmetallic Luster — Talc, Tryptophane, Bromite, Tyroline, Urgonite, Cerussite, Canchite, Nepheline, Crysoberyl.

Also Calcite, Arsenite, and many hydrous silicates, phosphates, etc.

2. Hard Minerals. — Minerals whose hardness is equal to or greater than 7 (Quartz = 7).

The following minerals are here included:

LISTED NONMETALLIC

| | | | |
|-------------|-------|-------------|-------|
| Quartz | 7 | Hallbergite | 7.5 |
| Tourmaline | 7 | Zircon | 7.5 |
| Fluorite | 7 | Asarsite | 7.5 |
| Hydroxide | 7 | Pyrite | 7.5-8 |
| Calcite | 7-7.5 | Lawsonite | 7.5-8 |
| Hauynite | 7 | Thymite | 7.5-8 |
| Zircon | 7 | Uranite | 7.5-8 |
| Hyacinth | 6.5-7 | Hyacinth | 7-8 |
| Tryptophane | 7-7.5 | Selenite | 8 |
| Canchite | 6.5-8 | Talc | 8 |
| Cerussite | 7-7.5 | Thymite | 8 |
| Hydroxide | 7-8 | Canchite | 8.5 |
| Hydroxide | 7-8 | Canchite | 9 |
| Hydroxide | 7-8 | Canchite | 10 |
| Hydroxide | 7-8 | Canchite | 10 |

The following minerals have hardness equal to 6 to 7 or 6.5-7

Lepidolite, Indurite, Iron, Selenite.

LISTED NONMETALLIC — Argonite, Urgonite, Baryte, Eucrase, Canchite, Chlorite, Diaspore, Epilote, Epilote, Forsterite, Selenite, Indurite, Eucrase, Silimanite, Spinelite, Trimerite.

III. SPECIFIC GRAVITY

Attention is called to the remarks in Art. 307 (p. 221), on the relation of specific gravity to chemical composition. Also to the remarks in Art. 308 as to the change of specific gravity arising to increase of metallic and non-metallic matter respectively. The species of each of the separate lists of Table II of minerals classified with reference to crystallinity are arranged in order of increasing specific gravity. Hence the lists give at a glance minerals distinguished by both low and high density.

IV. LUSTER (See Art. 371, p. 273)

Metallic — Native metals, most Sulphides; some Oxides, those containing iron, manganese, lead, etc.

Submetallic — Here belong chiefly certain iron and manganese compounds, as Ilmenite, Ilvaite, Cobaltite, Pinitite and allied species, Wodwanite, Braunitz, Hausmannite. Also Hematite, Limonite, etc.

Adamantine — Here belong minerals of high refractive index. (a) Some hard minerals. Diamond, Corundum, Cassiopeite, Zircon, Rutil, etc. b Many species of high luster, as compounds of lead also of silver, copper, mercury. These, Cerussite, Anglesite, Plumbopinitite, etc. Cerargyrite, Cuprite, some Cinnabar, etc. c) Also certain varieties of Sphalerite, Trinitite and Chalcocite.

Metallic-Adamantine — Pyrrargyrite; some varieties of the following. Cuprite, Cerussite, Tetrahedrite, Rutil, Hematite.

Resinous or Waxy — Stannite, Sulphur, Flusite, Serpentine, many Phosphates.

Vitreous — Quartz and many Silicates, as Garnet, Beryl, etc.

Pearly — The foliated species. Talc, Baryte, Pyrophyllite. Also for cleavage surfaces, especially the following. Asphurite, Stibite, Hematite. Also, some prominent native Carbonate, Phosphate, some Sulphate, and others.

Silky. — Some fibrous minerals, as Opuntia, Cocco, also Asbestos; Malachite.

V. COLOR

The following lists may be of some use in the way of suggestion. It is to be noted, however, that exposure to the action of atmospheric agents, or surface change may alter the effect of color. For this, among the rules of comparison under particularity, no sharp line can be drawn between colors slightly different, and many varieties of color due to the case of a single species. For these reasons the lists, though comparatively extended, could make any claim to completeness.

a) METALLIC LUSTRE

Silver-white, Tin-white — Native Silver; Native Antimony, Arsenic and Tellurium, Anagaitz, Arsenicite and Lollingite, several sulphides, arsenides, etc., of cobalt, of nickel, of Colalite, several some Tellurides, Bismuth orebluish. No sharp line at be drawn between these and the following groups.

Steel-gray — Plumbite, Magnetite, Chalcocite, Sphalerite, Bournonite.

Black-gray — Melanconite, etc.

Lead-gray — Many sulphides, as Galena bluish, Sulphate, many Sulphammonites, etc., as Limonite, and Dufrenoyite, etc.

Iron black — Cuprite, Tetrahedrite, Pyrrhite, Stephanite, Enargite, Pyrrhite, Mag.

Black with iridescent tints — Ilmenite, Limonite, Chalcocite, Tantalite, etc. Wodwanite, Ilvaite, Trinitite, etc. The colorings are usually brownish black. Braunitz, Hausmannite.

Copper red — Native copper.

Brown-red — Bournonite (which sometimes gives a purplish tint); Niccolite.

Bronze-yellow — Pyrrhite, Pyrrhite, Breithauptite.

Brass-yellow — Chalcocite, Millerite, Limonite, Talc brass-yellow: Pyrrite; Marcasite is whiter than Pyrrite.

Gold yellow — Native gold, chalcocite and pyrrite sometimes are mistaken for gold.

Streak — The following subsection of metallic luster are notable for the color of their streak.

Cinnamon-red — Pyrrhite.

Cherry-red — Monargyrite.

Dark Red — Hematite, Cuprite; some Cinnabar.

Scarlet — Cinnabar usually non-metallic.

Dark Brown — Magnetite, Hematite, Chalcocite.

Yellow — Limonite.

Tarnish. — The following are conspicuous for their bright or variegated tarnish. Chalcocite, Bournonite, purplish tints, Tetrahedrite, some Limonite.

(b) Nonmetallic Lenses

Colorless. - In Crystalline Quartz, Calcite, Aragonite, Gypsum, Cerussite, Anglesite, Albite, Barite, Adularia, Topaz, Apatite, etc., Native and other Zeolites, Celestite, Diaspore, Nephelite, Monazite, Calaverite, Crocoite, Phenacite, etc.

MASSIVE QUARTZ GRANITE (gneiss), Hyalite, biotite and

White. Crystals. Anhydrous. Lysine. Pyrazole dipeptide, usually crystalline.

Muscle Candy Milky Quartz Pendulums, especially Albite, Quartz, Cerussite.

Respirato, Talc, Mercurbaurin, Magnesia has ante, Amblygo, etc etc

Но. — Бачаин Б. з. Азатле Чогулте

Systematic Index to the Tenthredinidae

AYUM-B-ON LAKU, Ayutla Lakus Las, Tuxtepec.

PROCESSES: Sapphire, Kyanite, Cordierite, Azurite, Chalcanthite and many copper compounds.

547-р. и MOUNTAIN-BLUE Herb. Celanite

NEW YORK American Institute of Graphic Arts

Common Name: Amazon-stone, Chrysocolla, Canarian, Smithsonite, name Turquoise, Beryl.

Green Blackish Green Yellow Brownish Pyrozeus Anhydride

EMERALD-GREEN Beryl, Emerald, Malachite, Diopside, Almandine and many other precious gemstones. See page 10.

Второй (и третий) раз в жизни, в 1990-1991 гг., в США и в Европе, я посетил все эти страны. Вспомогательные материалы к лекциям, а также материалы к семинарам, посвященным изучению истории культуры, можно найти в Интернете по адресу: <http://www.chem.msu.ru/~chem/chem.htm>.

San Lorenzo, Chiriquito, Chiriquito, near Toluca.

NE 4TH AND JUDITH. BIRTH: UNKNOWN. DEATH: UNKNOWN.

SPRINGBORN Tule, Garnet, Chrys. gran., & minute Garnet ls., Pyrox. ls.

DATA ACQUISITION: 100000

CHAM-GREEN, PVT. INC. 1000 Weyburn, Ontario, Canada

Consolidation—Aynscombe and Poyser, that a contract entered into in January, 1906,

YELLOW GREEN to OLIVE-GREEN. Dots sparse, Chrysobryl, Chrysobryl above
green. Chlorite. Surface. I. and II. 100 to 150 to 200 to 250 to 300 to 350 to 400 to 450 to 500 to 550 to 600 to 650 to 700 to 750 to 800 to 850 to 900 to 950 to 1000 to 1050 to 1100 to 1150 to 1200 to 1250 to 1300 to 1350 to 1400 to 1450 to 1500 to 1550 to 1600 to 1650 to 1700 to 1750 to 1800 to 1850 to 1900 to 1950 to 2000 to 2050 to 2100 to 2150 to 2200 to 2250 to 2300 to 2350 to 2400 to 2450 to 2500 to 2550 to 2600 to 2650 to 2700 to 2750 to 2800 to 2850 to 2900 to 2950 to 3000 to 3050 to 3100 to 3150 to 3200 to 3250 to 3300 to 3350 to 3400 to 3450 to 3500 to 3550 to 3600 to 3650 to 3700 to 3750 to 3800 to 3850 to 3900 to 3950 to 4000 to 4050 to 4100 to 4150 to 4200 to 4250 to 4300 to 4350 to 4400 to 4450 to 4500 to 4550 to 4600 to 4650 to 4700 to 4750 to 4800 to 4850 to 4900 to 4950 to 5000 to 5050 to 5100 to 5150 to 5200 to 5250 to 5300 to 5350 to 5400 to 5450 to 5500 to 5550 to 5600 to 5650 to 5700 to 5750 to 5800 to 5850 to 5900 to 5950 to 6000 to 6050 to 6100 to 6150 to 6200 to 6250 to 6300 to 6350 to 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Yellow No. 3111 1/2" x 1/2" x 1/2" 1/2" x 1/2" x 1/2"

CHANGING THE LAW 23

Silvery yellow and Wax yellow Wax yellow Topaz, Sulphur, Fluorite, Chrysoprase, Wadsworthite, Wadsleyite, Vanadinite, Urtapelite, Carnotite, Baryte, Cymophane, Chondrodendrite
Thomsonite; Dowsomite etc.

Mo. h. St. laurente. Rurcite: Conchata

CHIEF DE LOUVE: ...

Red Herring, Rye, cornmeal, Rabbit species, maul, Garnet, Proulxite, Yarn
dun, Scheldete, Chemist

(2) 1997年12月31日以前竣工的已完工程

H4 15TH FEB 1950 4:50 PM (2000116)

Chlorophyll *a* and *b* were determined using a Shimadzu UV-1601U ultraviolet-visible spectrophotometer. Chlorophyll *a* was determined using the equation: $\text{Chlorophyll } a (\mu\text{g mL}^{-1}) = 12.7 \times \text{OD}_{665} - 2.69 \times \text{OD}_{646}$ and chlorophyll *b* was determined using the equation: $\text{Chlorophyll } b (\mu\text{g mL}^{-1}) = 22.9 \times \text{OD}_{646} - 8.46 \times \text{OD}_{665}$ (Morel and Allard 1992).

Содержание: мрамор, известняк, гипс, кварц, флюорит

439 LUT 42 LPS 17.5 1000 1000

Experiments: Simple Circuit to read other's

It is a plant with a thick, woody stem, and the leaves are small, dark green, and glossy. The flowers are small, white, and fragrant. The fruit is a small, round, red berry. It is a common plant in the tropics, and is often used in traditional medicine.

PROV. 31:26-27 RUL. TO LACS: 10/21/10, RUL. 10/21/10

§ 87(2)(b) none of the above. Which of the various domestic courts (baptist)

Still, it's not a bad idea to have a few more than you need.

2. no. written (20) number 14 the current, September, 2012 to K 14

Brown. Red and Browns. Some Garnet, some Spineloid, some fine Garnetite
[a] de

Содержание: Актиниды, Зюльте, Пятнашвили

Yellowish brown Silicate and related, arkosites, Sphalerite, Jasper, Limestone
Gneiss, Tourmaline Very rare. Chondrite, Sphalerite

B A KIM Brown Tanto, some Sugar, Sugarite

[illegible]

Black Tourmaline, Black Garnet, melanite, some Mn, especially bristly, some
some thymolite. Pyroxene and Quartz. There are mostly greenish or brownish
further, some Sphalerite and some kinds of Chlorite, varying from strongly brown to black.

also Allantite, Samarskite. Some black minerals with submetallic luster are mentioned on p. 820.

Streak — The streak is to be noted in the case of some minerals with nonmetallic luster. By far the majority have, even when deeply colored in the mass, e.g. Tourmaline, a streak differing but slightly from white. The following may be mentioned:

CRANE'S YELLOW ~~Zinnite~~ Crocoite

COCHINEAL-RED Pyrope, Garnet and Prase.

ROSE-COLOR ~~Quartz~~ Opal

BROWNISH-RED Chrysotile, Hematite.

BROWN ~~Montmorillonite~~

The streak of the various copper, green and blue minerals, as Malachite, Azurite, etc., is about the same as the color of the mineral itself though often a little paler.

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